Exclusive, Diffraction, & Tagging Meeting

Update on VM production in eA

20 May 2024

Zvi Citron[1], Eden Mautner[1], Michael Pitt[1,2]
[1]*Ben Gurion University of the Negev (Israel)*
[2]*The University of Kansas (USA)*

אוניברסיטת בן-גוריון בנגב
جامعة بن غوريون في النقب
Ben-Gurion University of the Negev

KU

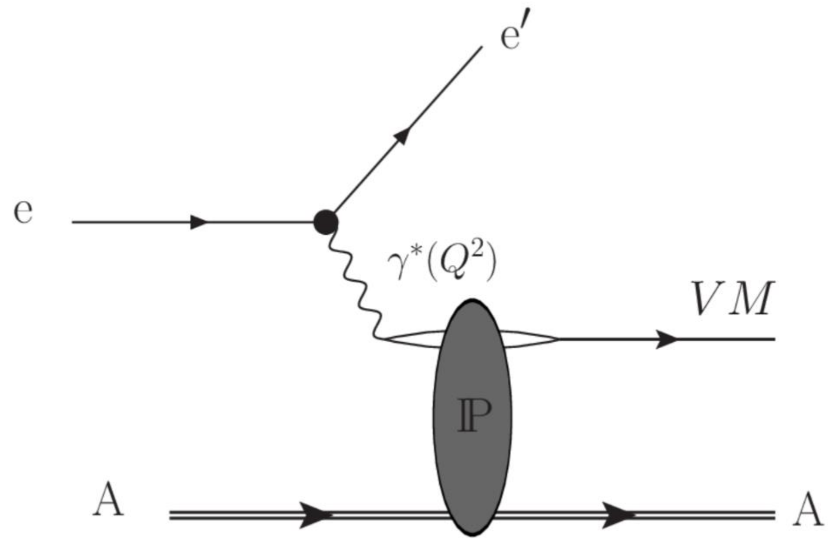
Outline

- At Ben Gurion University, we aim to deliver several physics case studies for the upcoming TDR. The following will be discussed today:
  - Coherent production of J/ψ
  - Soft photons
  - t-reconstruction and Low-Q2 event selection
- Next time, we will focus on the following topics:
  - Ion tagging in RP, photon-photon interactions, t-reconstruction

Introduction

Goals

- Probing the low-X structure of the nucleus
- Probing spatial parton structure of nuclei



Methodology

- Measuring coherent vector meson (VM) production
- Differential cross-section $(d\sigma/dt)$ as a function of momentum transfer → spatial distributions of gluons

Coherent and incoherent production

Event Kinematics

Reconstruction of parameters of interest:

e – incoming electron (**determined by beam parameters**)

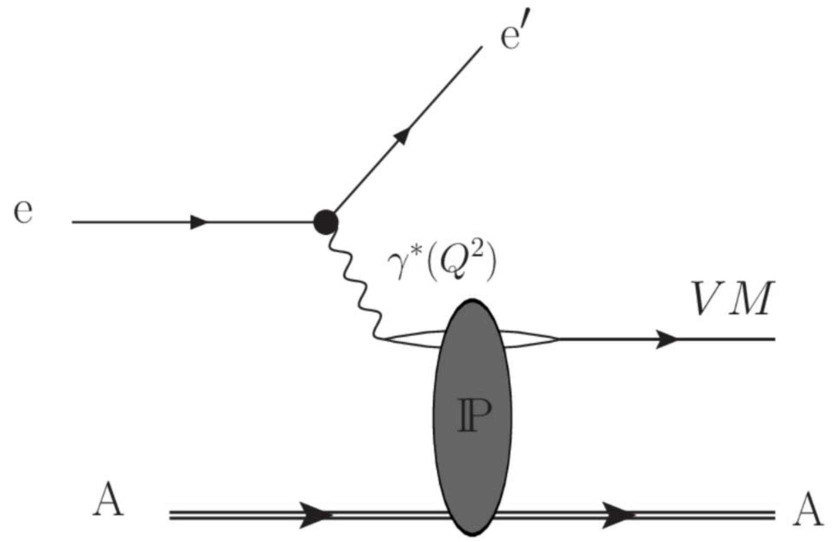
e' – outgoing electron (**measured**)

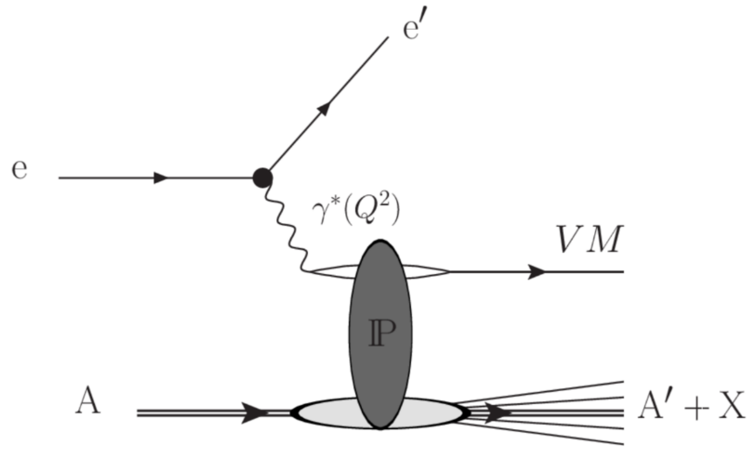
VM – vector meson (**measured**)

- Energy scale $Q2 = -(e - e').M2()$
- Momentum transfer $-t = (VM - (e - e')).M2()$

Challenges

- Rejection of incoherent events
- Reconstruction of t parameter

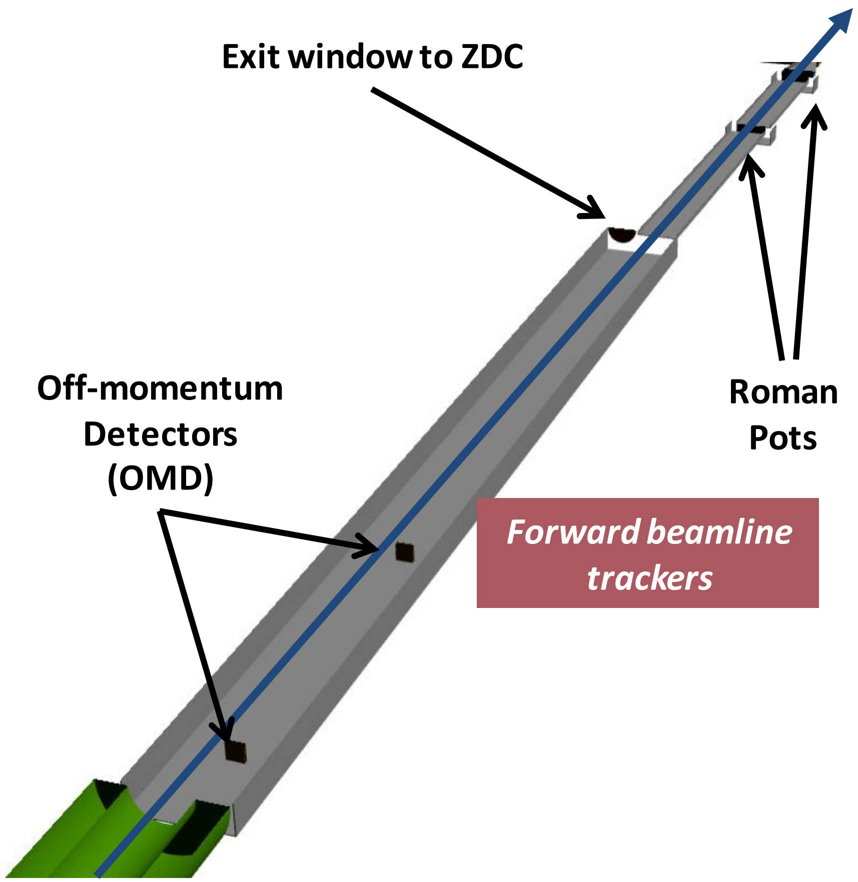


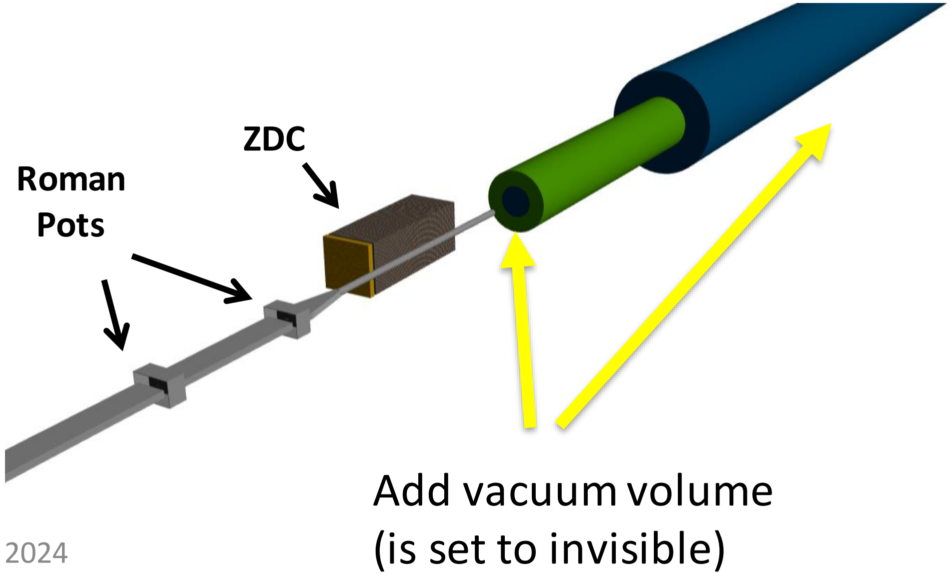


Introduction

Simulation updates *(crucial for vetoing program)*

- New FF design (merged by Alex since Apr 4 PR-665), adding vacuum inside the hadron beampipe
- Extending the vacuum for z>40 (RP-720), to be merged soon…





Coherent production

Signal simulation

eStarlight: https://github.com/michael-pitt/estarlight/tree/FixIonPDG

W_MAX = -1   #Max value of w from HERA
W_MIN = -1   #Min value of w from HERA
W_N_BINS = 50   #Bins i w
W_GP_MAX = -1 #Max value of W_gp
W_GP_MIN = -1 #Min value of W_gp
EGA_N_BINS = 400
CUT_PT = 0 #Cut in pT? 0 = (no, 1 = yes)
CUT_ETA = 0 # Cut in Eta on VM decay products
PROD_MODE = 12   #narrow / wide switch (12 = coherent vector meson (narrow), 13 = coherent vector meson (wide))
N_EVENTS = 4000
PROD_PID = 443011 # 443011 - Jpsi->ee , 443013 - Jpsi->mumu,
PYTHIA_FULL_EVENTRECORD = 1 # Write full pythia information to output (vertex, parents, daughter etc).
QUANTUM_GLAUBER = 1 # Do a quantum Glauber calculation instead of a classical one
MIN_GAMMA_Q2 = 1.0
MAX_GAMMA_Q2 = 10.0
SELECT_IMPULSE_VM = 0   # Impulse VM parameter

Execution time:

No ions in the record: 2.01 s/Event
Standard: 183.20 s/Event
PR720 (add more vacuum): 16.23 s/Event

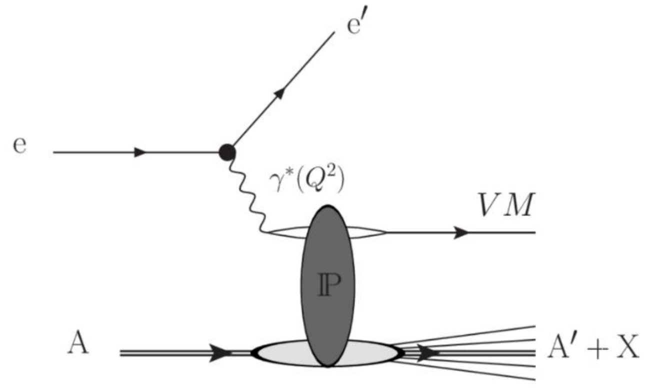
$$
\begin{aligned}
\sigma(Q^2 < 0.001) &= 73.907\ nb \\
\sigma(0.001 < Q^2 < 0.03) &= 25.496\ nb \\
\sigma(1 < Q^2 < 10) &= 9.652\ nb
\end{aligned}
$$

Low Q2 region is discussed latter

Background simulation

BeAGLE V1.03.02 (https://eic.github.io/software/beagle.html)

```
PROJPAR                                             ELECTRON
TARPAR       208.0     82.0
TAUFOR        10.0     25.0     1.0
FERMI         2         0.62    1      0
*
*         yMin    yMax   Q2Min   Q2Max   theta_Min theta_Max
L-TAG      0.01    0.95   1       10.0    0.0      6.29
*
* model selection (0=all, 1=rho,2=omega,3=phi,4=J/psi)
PYVECTORS     4
USERSET       15        9.0
MODEL                                               PYTHIA
* if PYTHIA model specify pythia input cards
PY-INPUT                                            S3VJL003
```



Execution time:

Standard: 320 s/Event

PR720 (add more vacuum): 35 s/Event

Using t-Filter for t<0.2

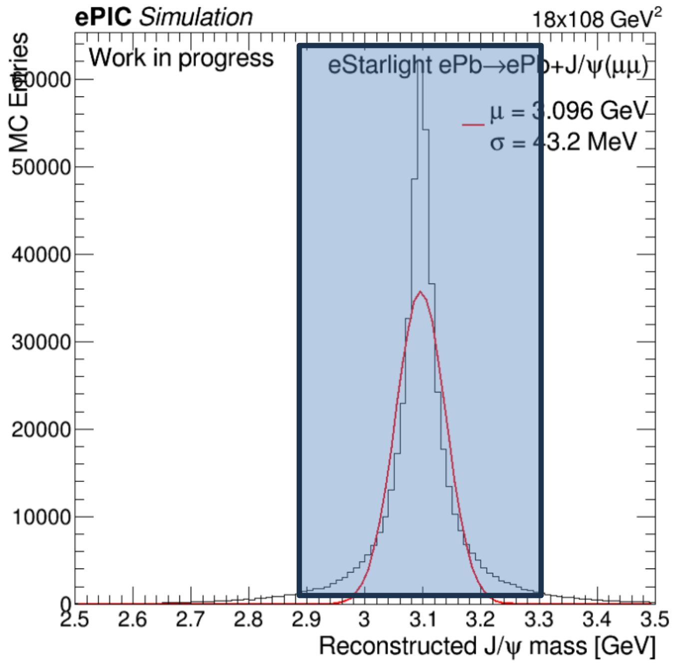
Filter efficiency ε~40%

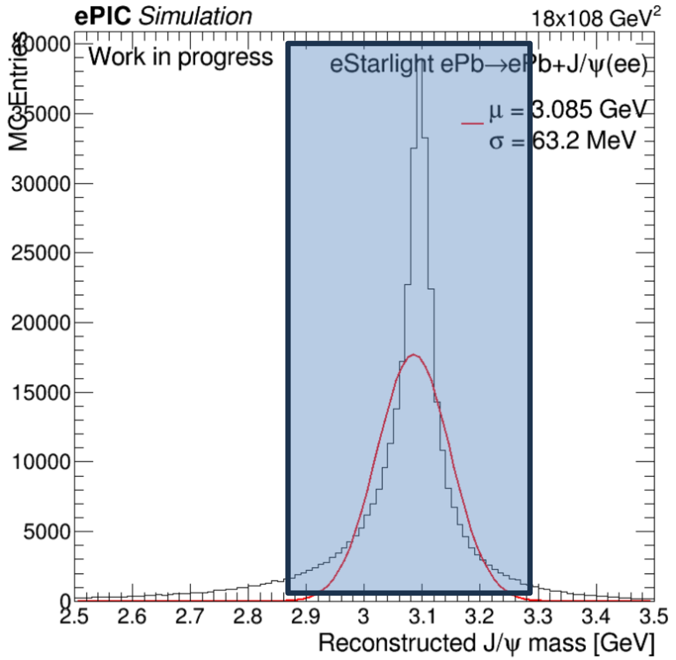
Analysis

Coherent event Selection

- 3 track events (in Barrel)
- J/psi mass window of 0.4 GeV (no PID)
- Veto activity in forward region (reco/hits):

B0 tracks, B0 clusters, Hits in OMD / RP, Ecal and Hcal ZDC Clusters





Signal efficiency for different lepton flavours:

Cut	electrons	Muons
3 tracks	0.973705	0.97383
VM mass cut	0.838785	0.898815
Veto FF Detectors	0.838745	0.898795

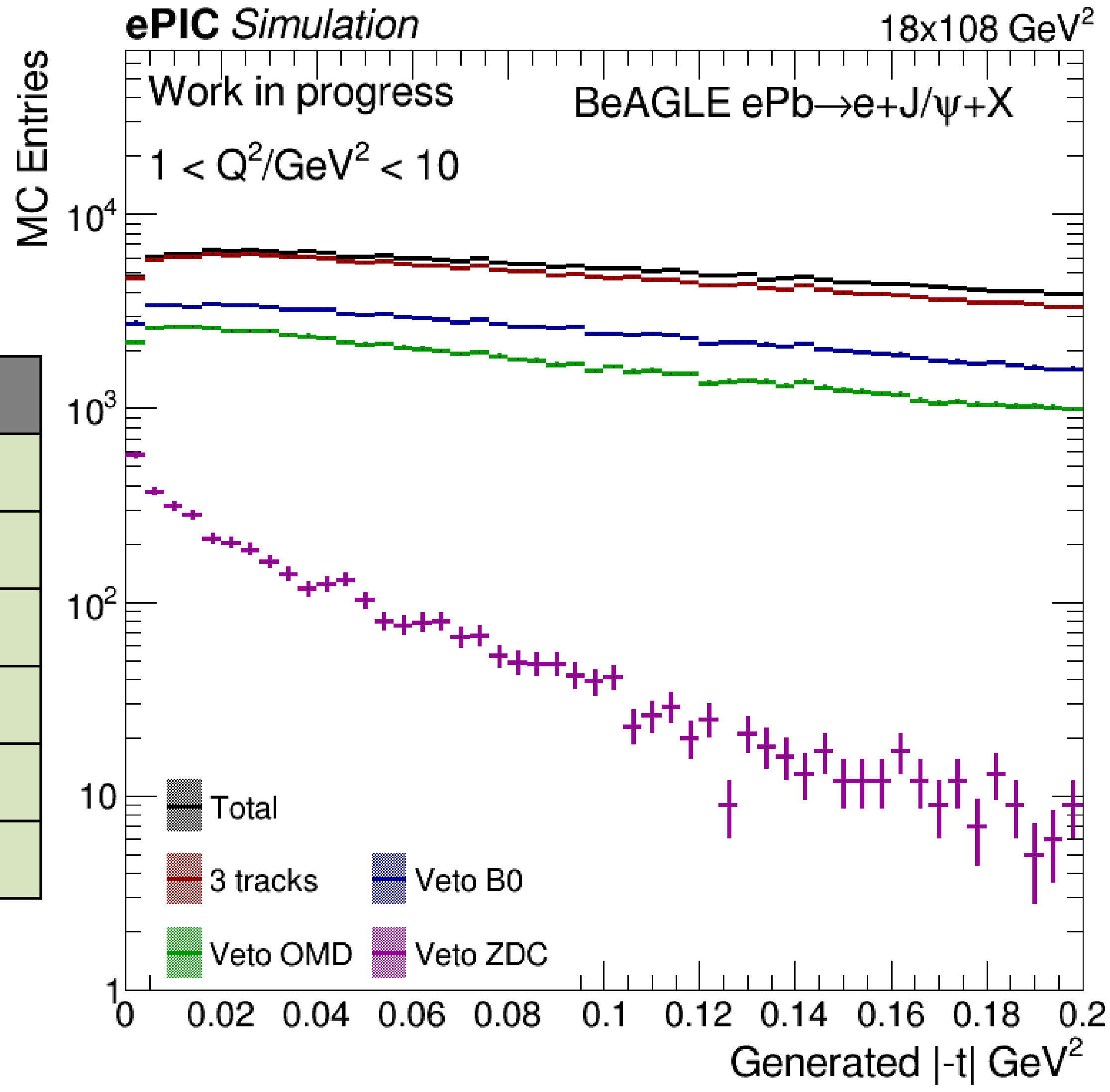
Incoherent rejection

- Modify the strategy of [2108.01694](2108.01694) (from object rejection to signal rejection)
- Work by Eden Mautner (in progress)

- Veto.1: no activity other than e^- and J/ψ in the main detector ($|\eta| < 4.0$ and $p_T > 100$ MeV/c) ;
- Veto.2: Veto.1 and no neutron in ZDC;
- Veto.3: Veto.2 and no proton in RP;
- Veto.4: Veto.3 and no proton in OMDs;
- Veto.5: Veto.4 and no proton in B0;
- Veto.6: Veto.5 and no photon in B0;
- Veto.7: Veto.6 and no photon with $E > 50$ MeV in ZDC.

Background efficiency based on ePIC FFD simulation

Cut	el+mu
3 tracks	0.914885
VM mass cut	0.827045
Veto B0	0.429656
Veto OMD	0.29286
~~Veto RP~~	~~0~~
Veto ZDC	0.013776

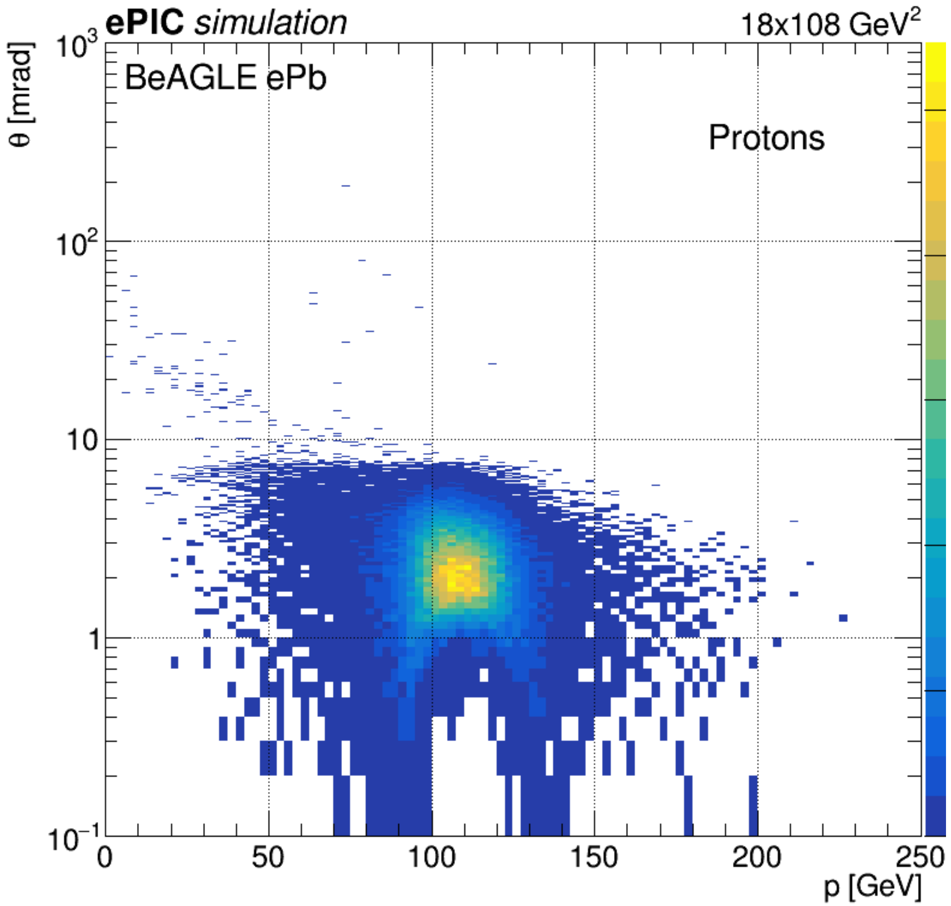


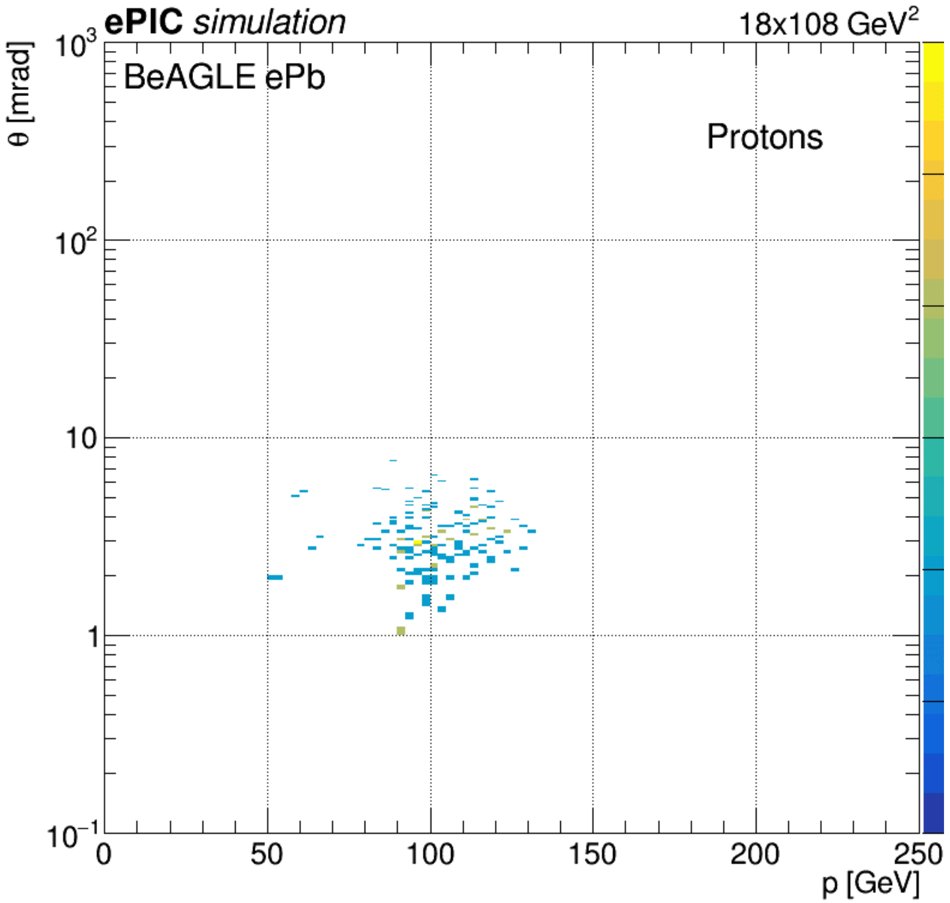
RomanPots response is investigated…

(See backup slide #22)

Rejection of forward particles

- Following the full event selection, the veto program has strong discrimination





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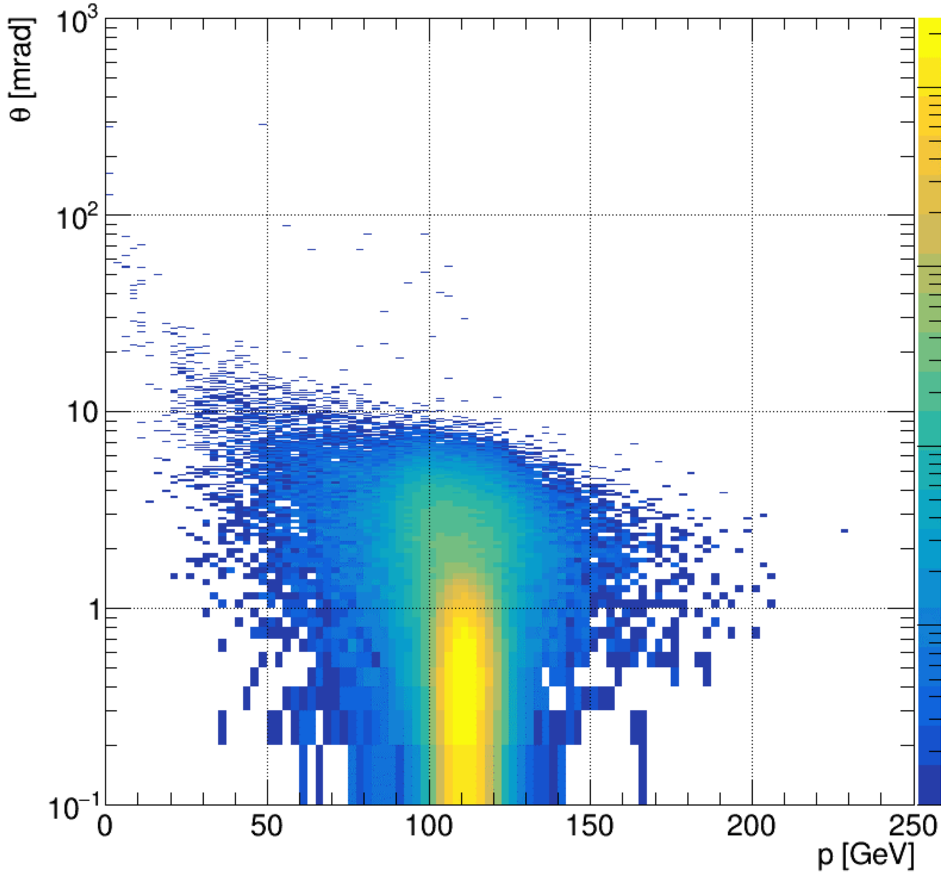

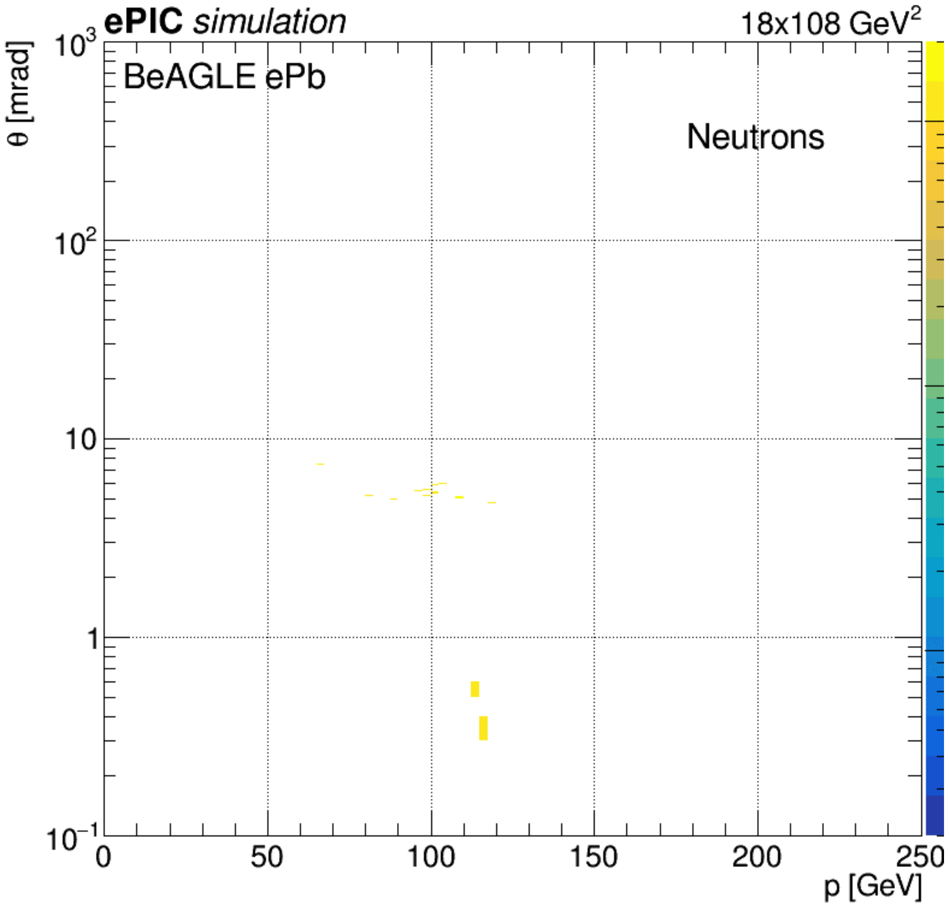

Rejection of forward particles

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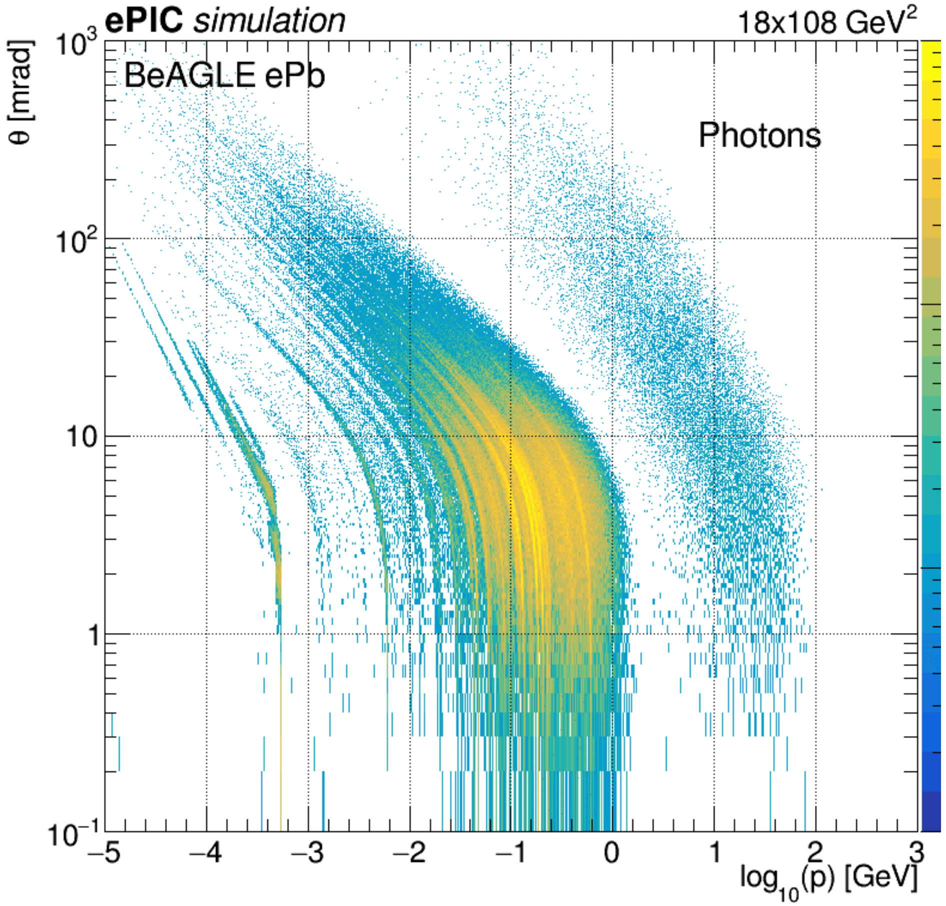
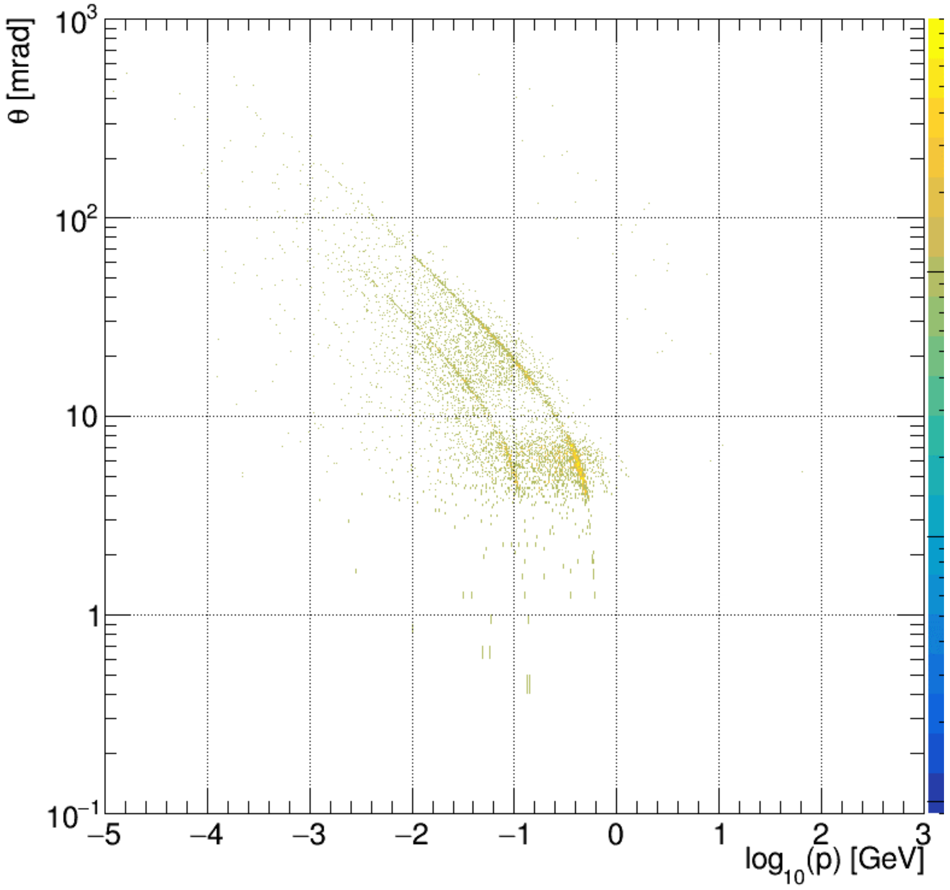
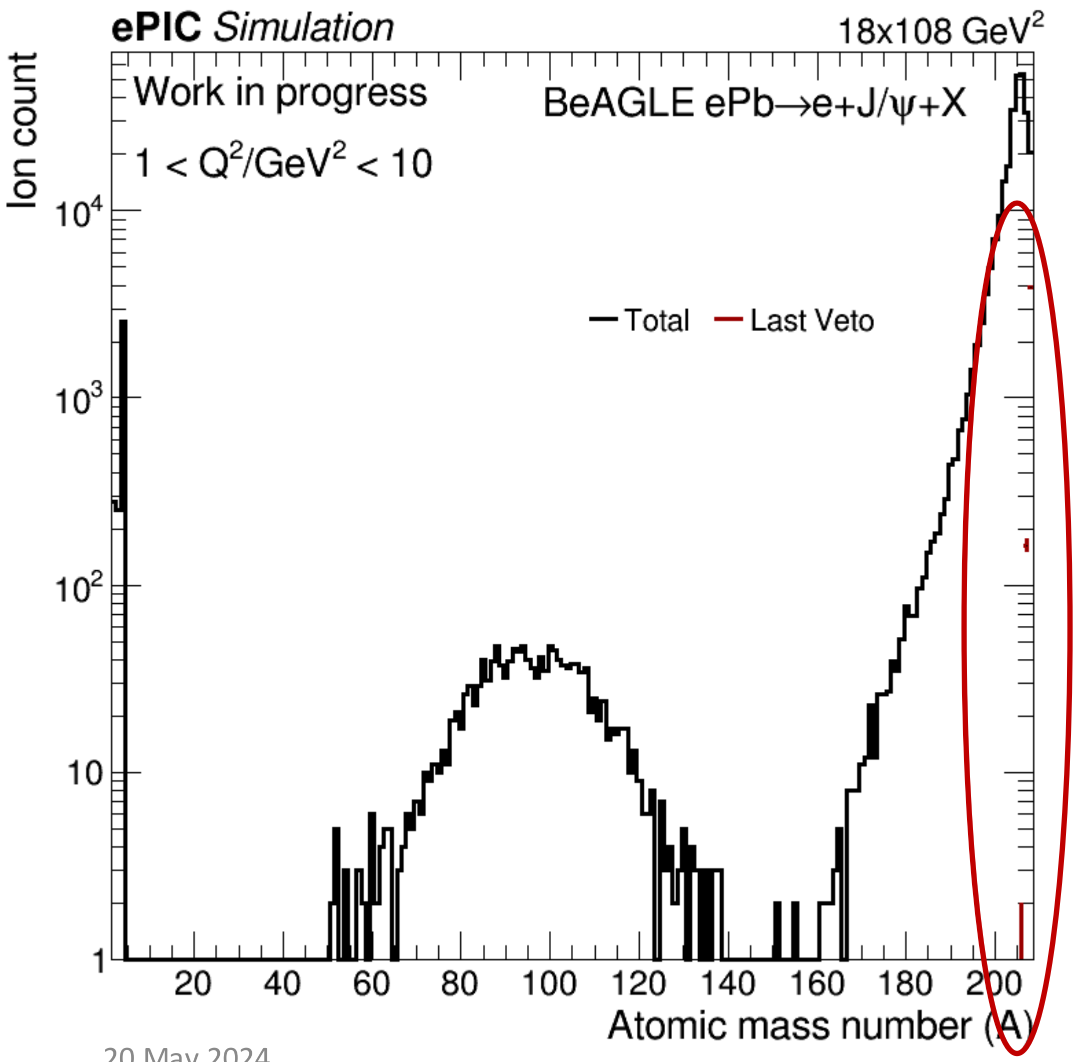


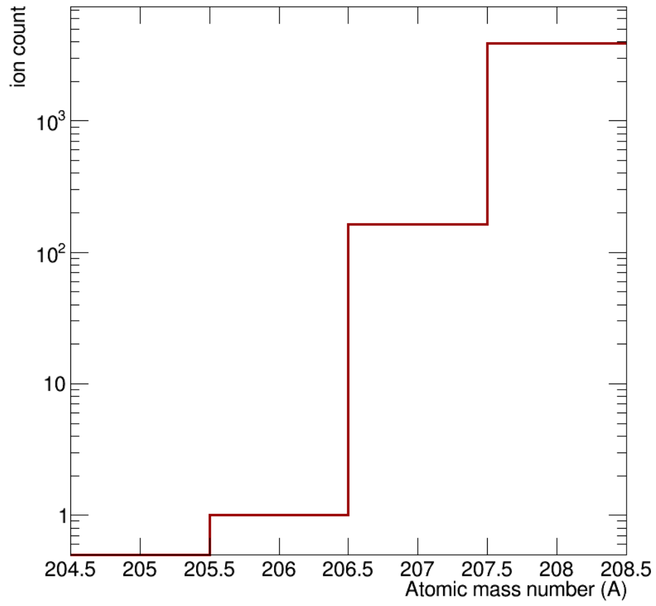


Signal purity

- Remaining backgrounds are mostly events with deexcited Pb ions:

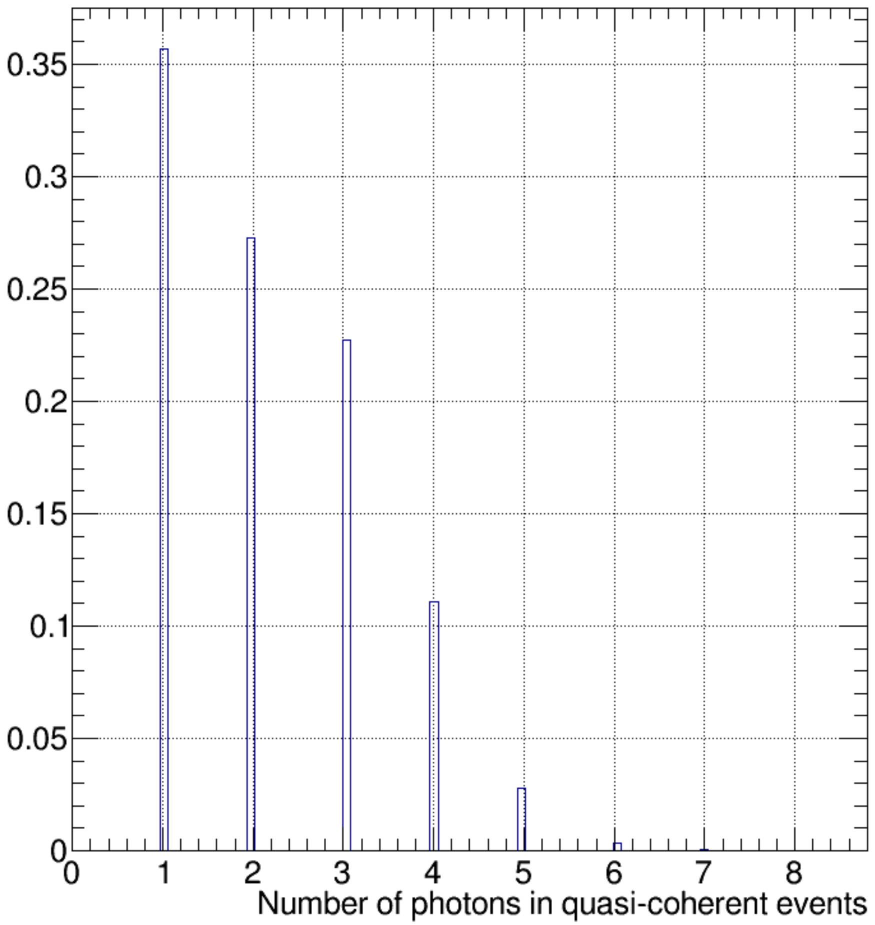


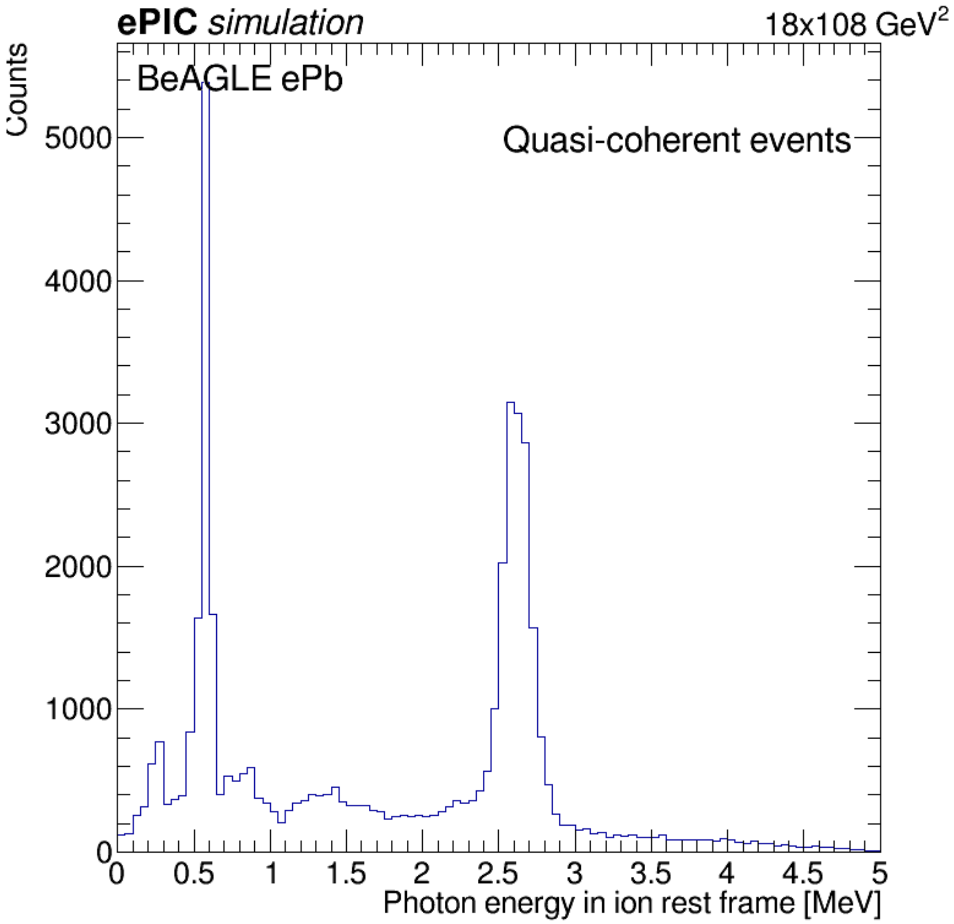
- It is not clear which kinematics such processes have
- We develop a dedicated analysis strategy to study these events



Quasi-coherent event analysis

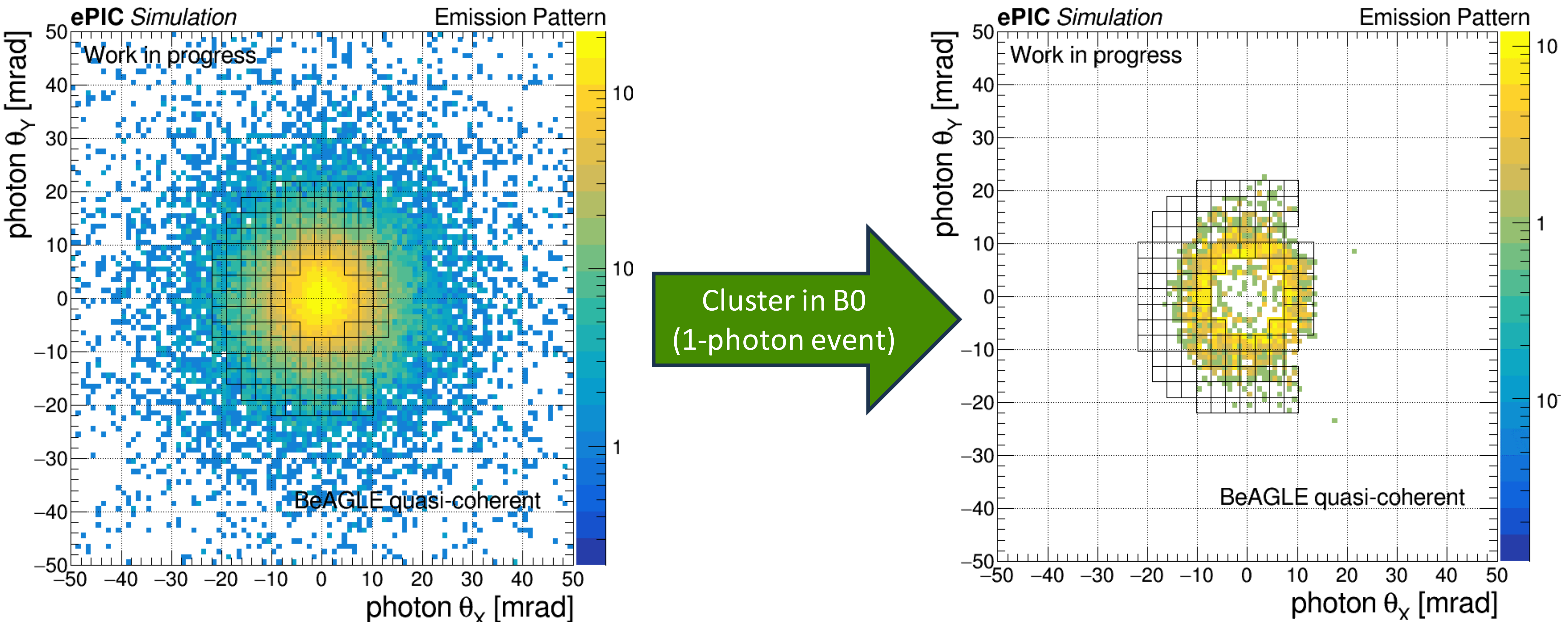
- Rather small photon multiplicity in BeAGLE, do we miss any other processes that contributes production of photons in association with vector mesons?





Quasi-coherent event analysis

- Most of the “background” events are quasi-coherent events



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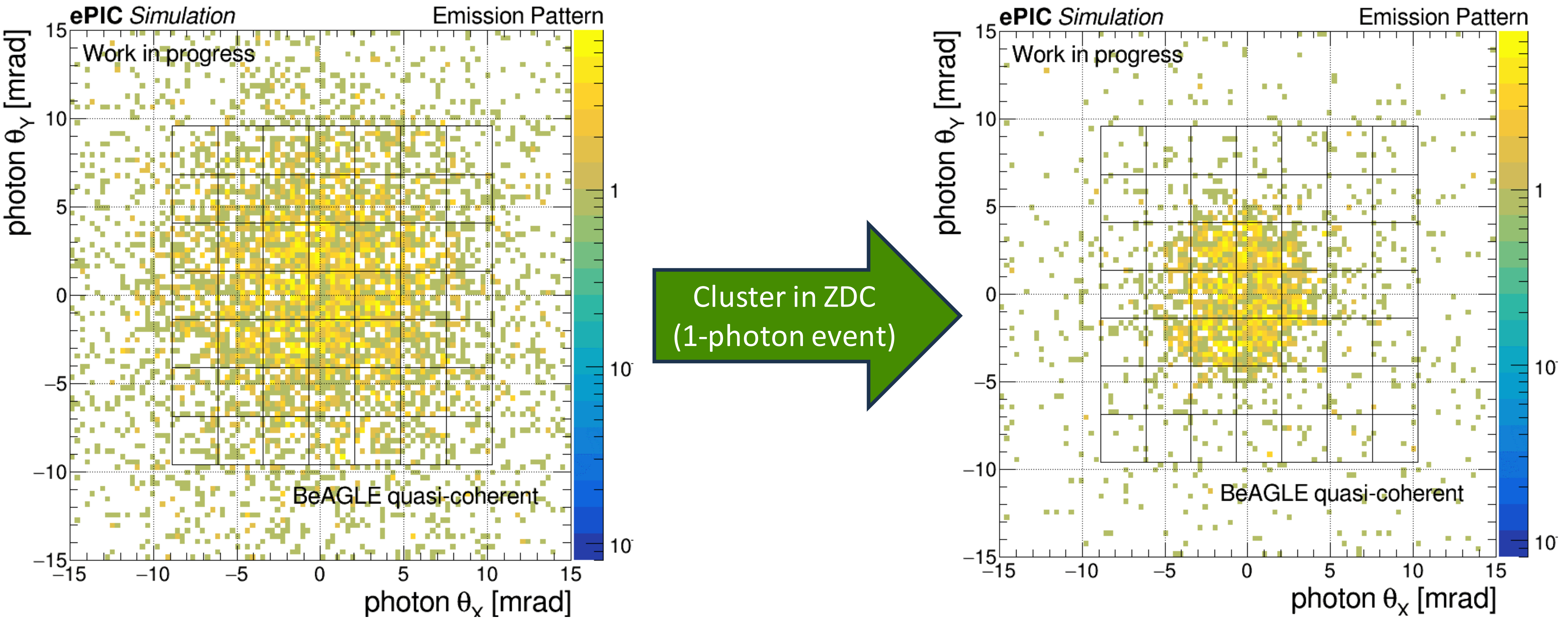
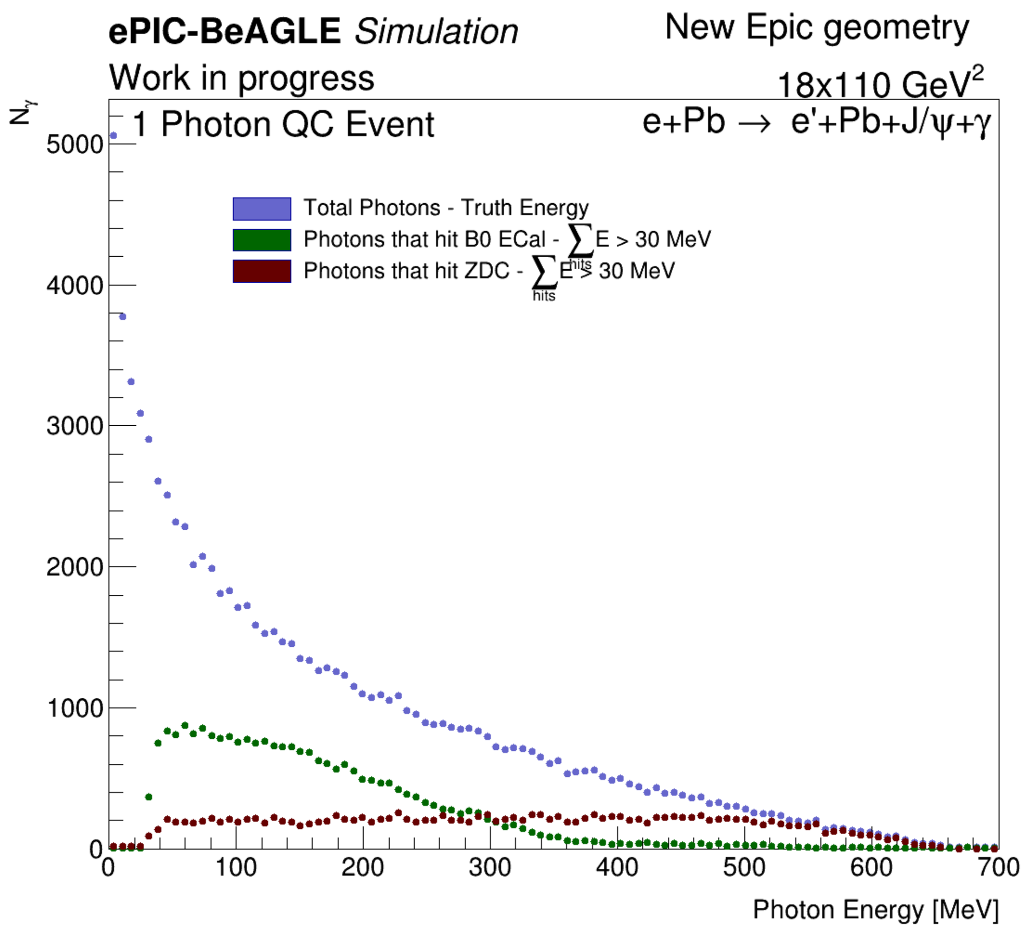
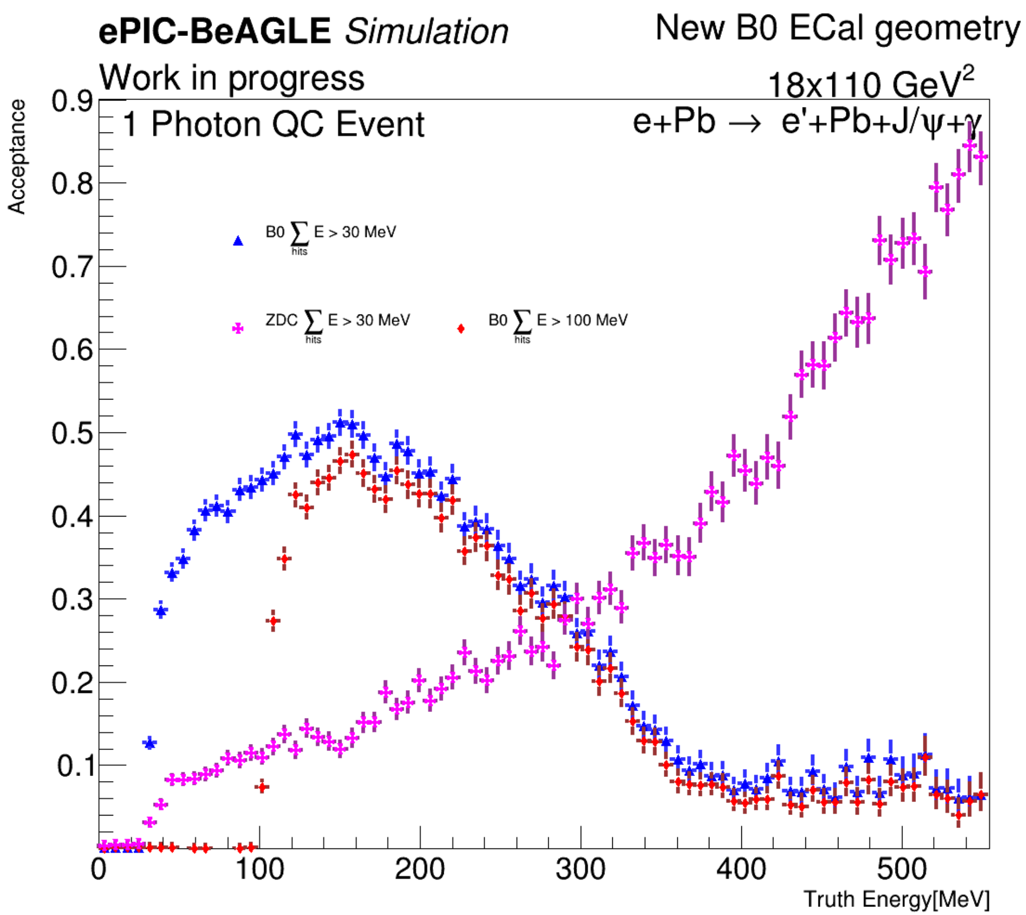


Quasi-coherent event analysis

- Good efficiency for those photons





Quasi-coherent event analysis

- Photon reconstruction in ion rest frame:
  - Reconstruction of photon 4-momentum → boost to the ion rest frame
  - Past studies showed B0/ZDC position resolution was sufficient
  - Currently EICRecon clustering algorithm in B0/ZDC has issues (see backup)
    - Once solved, we can check the energy resolution of soft photons

t-reconstruction

Analysis:

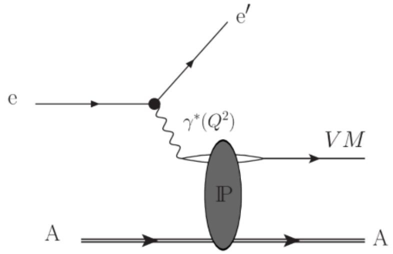
Another challenge in the analysis is to reconstruct the momentum transfer

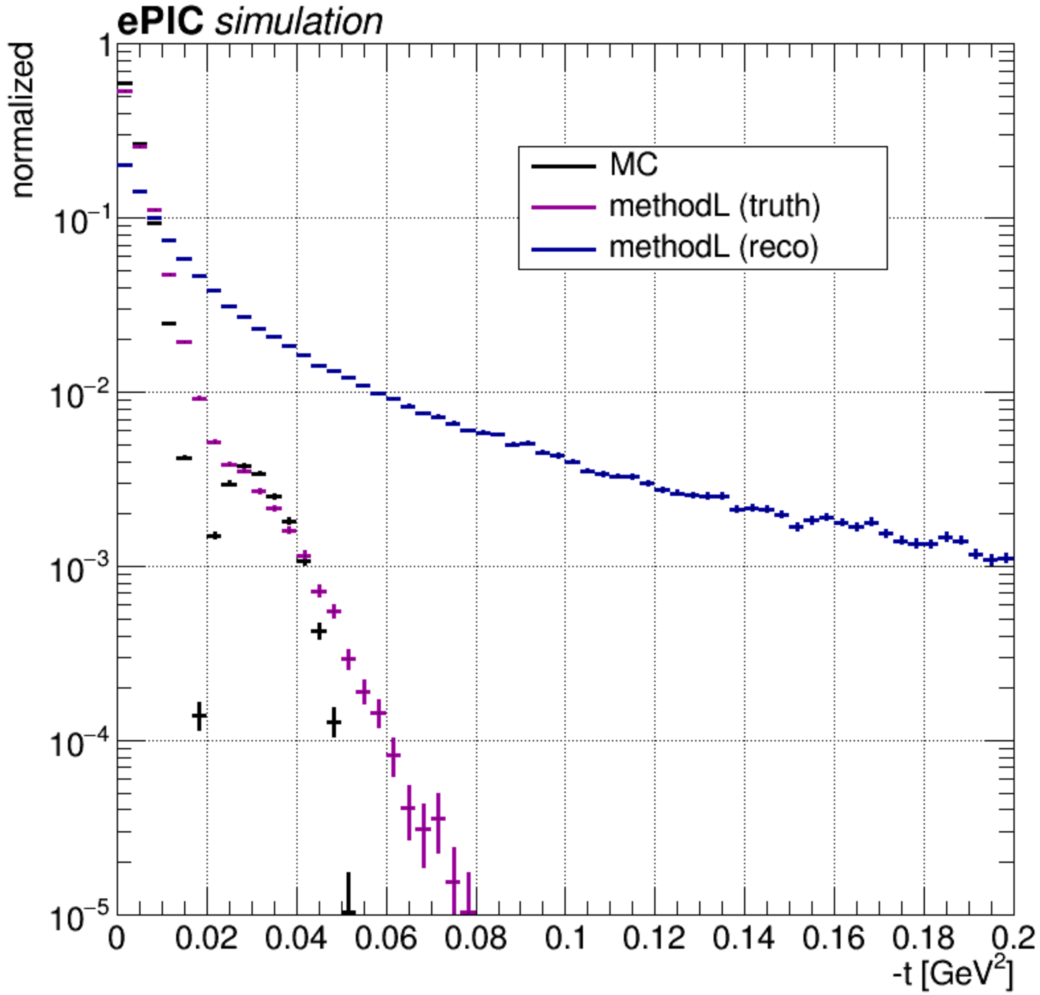
e – incoming electron (**determined by beam parameters**)

e' – outgoing electron (**measured**)

VM – vector meson (**measured**)

Momentum transfer –t =(VM −(e−e')).M2()



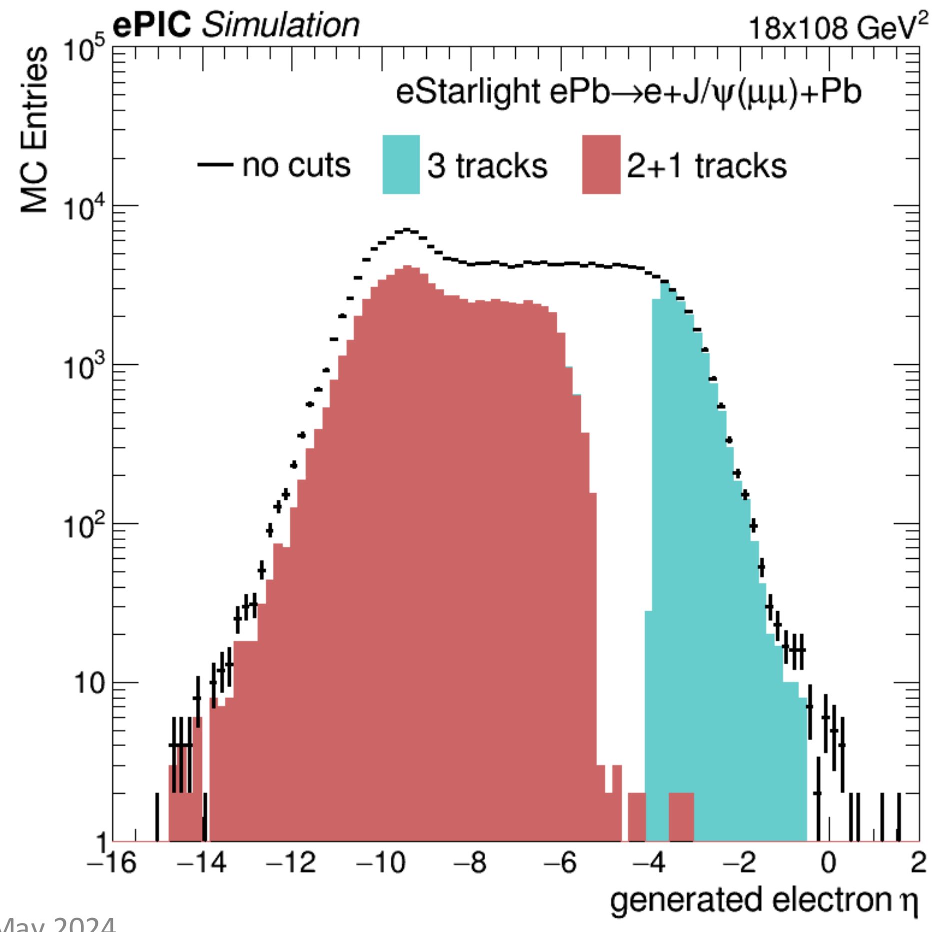


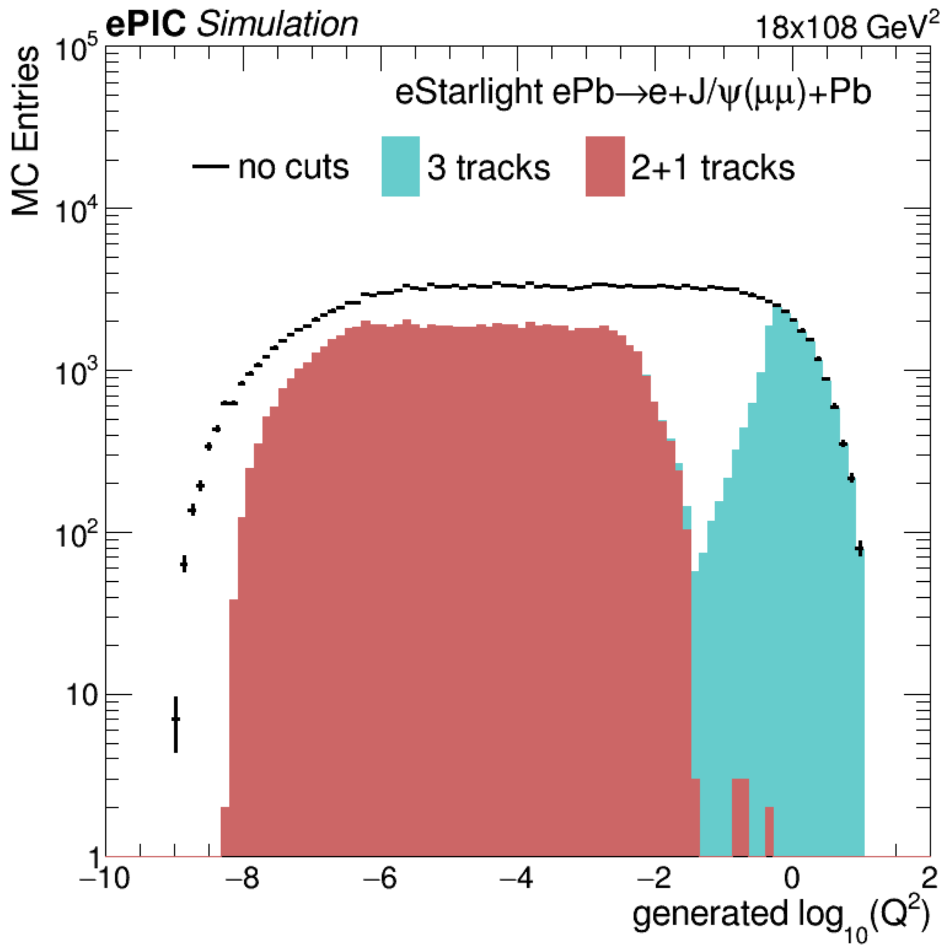
Using method L to reconstruct the momentum transfer:

- Already after the AfterBurner and truth inputs, we see small bias – Assumption that A=(0,0,PZ) is not correct

Q2 and electron scattering

- The phase-space can be further divided to two regions **Acceptance of low-Q taggers** and **Acceptance in central detector** (main analysis)





Q2 and electron scattering

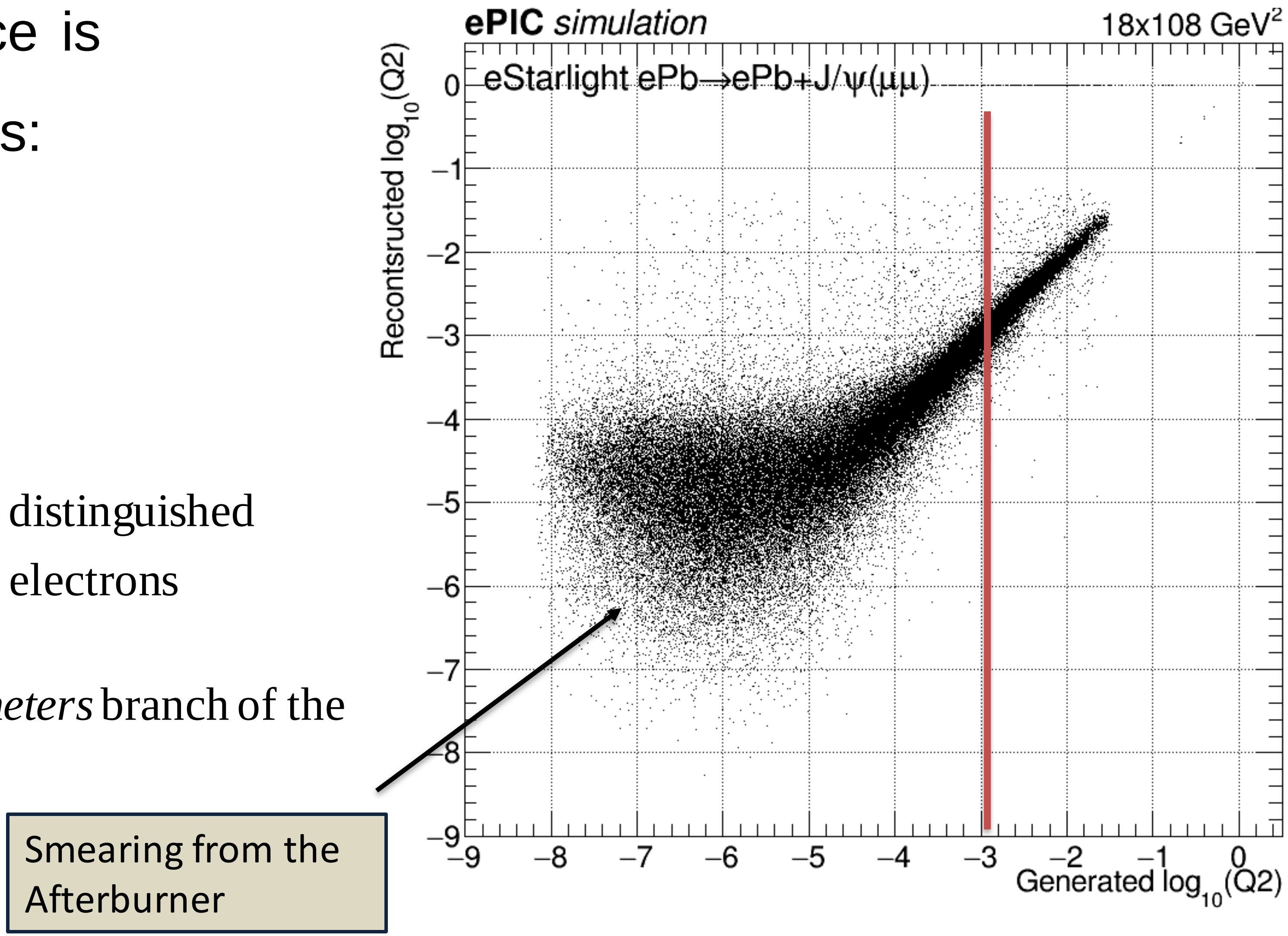
- The low Q2 tagger phasespace is further divided into two regions:

  0.001 < Q2 < 0.03

  low(Q2) < -3

<u>Low-Q2 tagger performance</u>:

- Electrons with log(Q2) < -3 cannot be distinguished
- At the design lumi, hundreds of brem. electrons produced every bunch crossing
- Using the *TaggerTrackerTrackParameters* branch of the EICRecon output

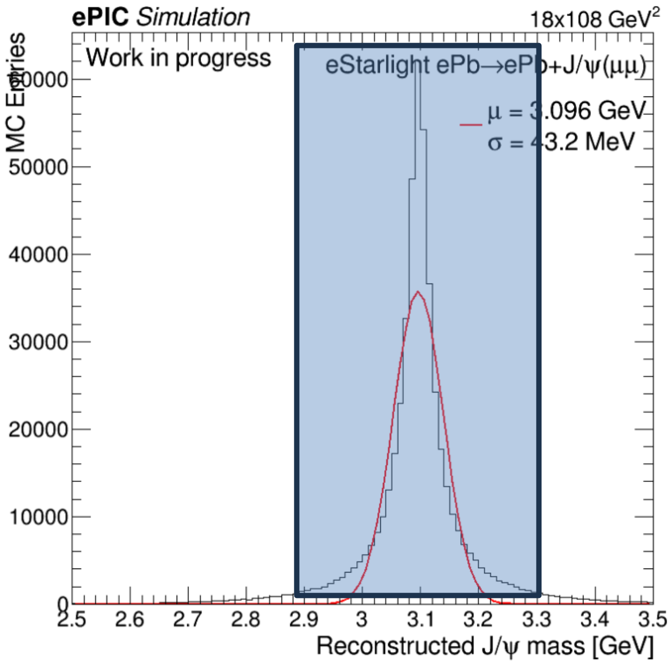


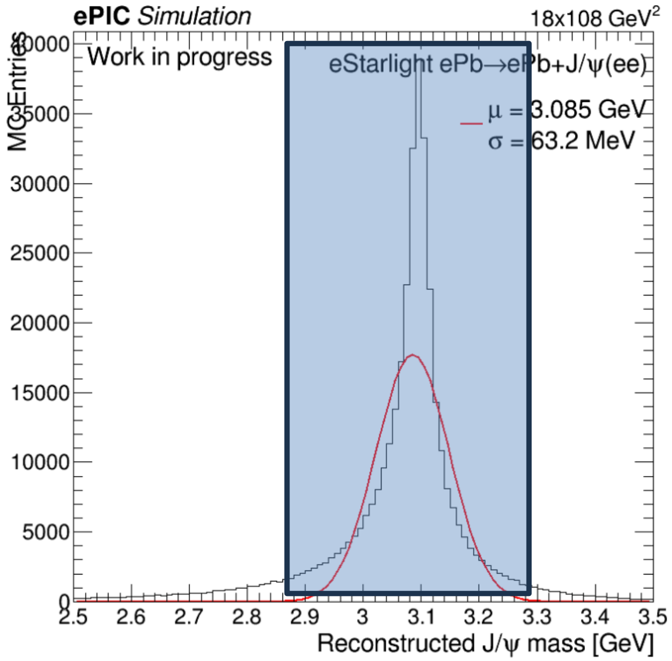
Analysis

Coherent event Selection

- 3 track events (with 2 tracks in |η|<4)
- J/psi mass window of 0.4 GeV (no PID)
- Veto activity in forward region (reco/hits):

B0 tracks, B0 clusters, Hits in OMD / RP, Ecal and Hcal ZDC Clusters





<u>Signal efficiency for different Q^2 regions:</u>

	electrons			Muons		
Cut	$Q^2<0.001$	$0.001<Q^2<0.03$	$1 < Q^2 < 10$	$Q^2<0.001$	$0.001<Q^2<0.03$	$1 < Q^2 < 10$
3 tracks	0.565585	0.338035	0.973705	0.566175	0.337	0.97383
VM mass cut	0.495305	0.29898	0.838785	0.52959	0.317285	0.898815
Veto FFD	0.495305	0.29897	0.838745	0.52959	0.31727	0.898795

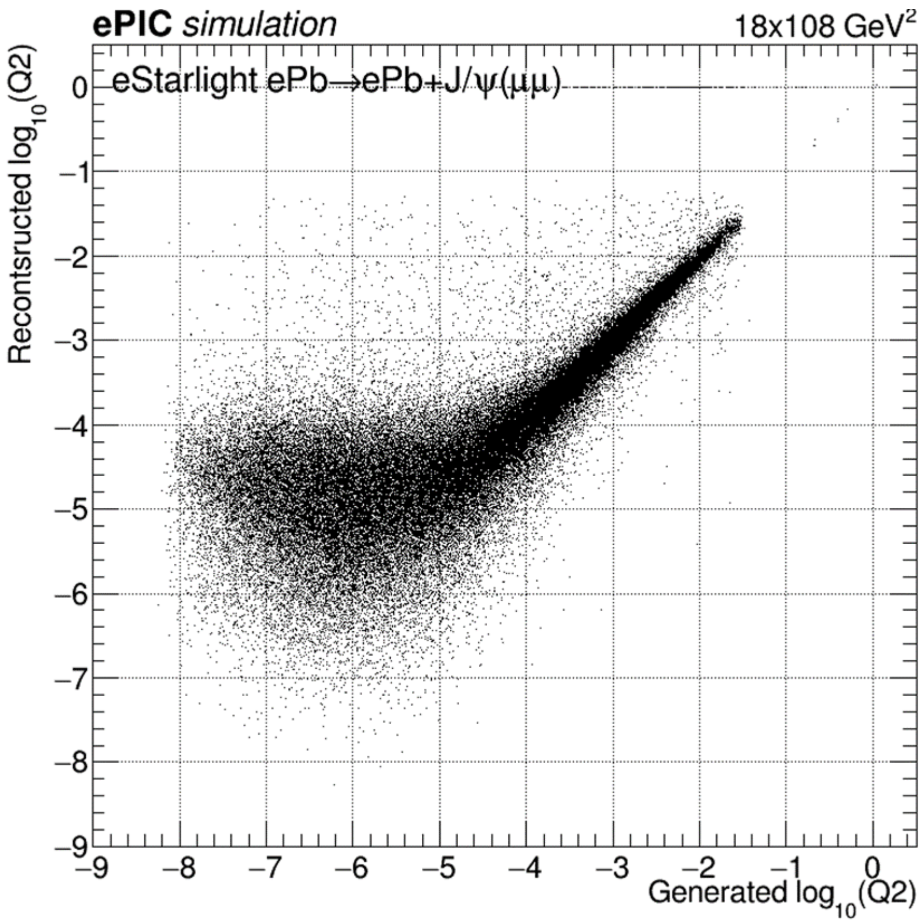
Event categorization

- Depends on the electron reconstructed eta (Barrel) or Q2 (Taggers)
  - Central detector: 9.6 nb x 0.9 ~ 8.6 nb
  - Low-Q2 taggers: 25 nb x 0.3 ~ 7.5 nb

Adding low-Q2 category double statistics

Reducing uncertainty from outgoing electron

- Tagging Very-Q2 region: need to estimate backgrounds
- Incoherent background has ~ similar rejection as for the high Q2 events



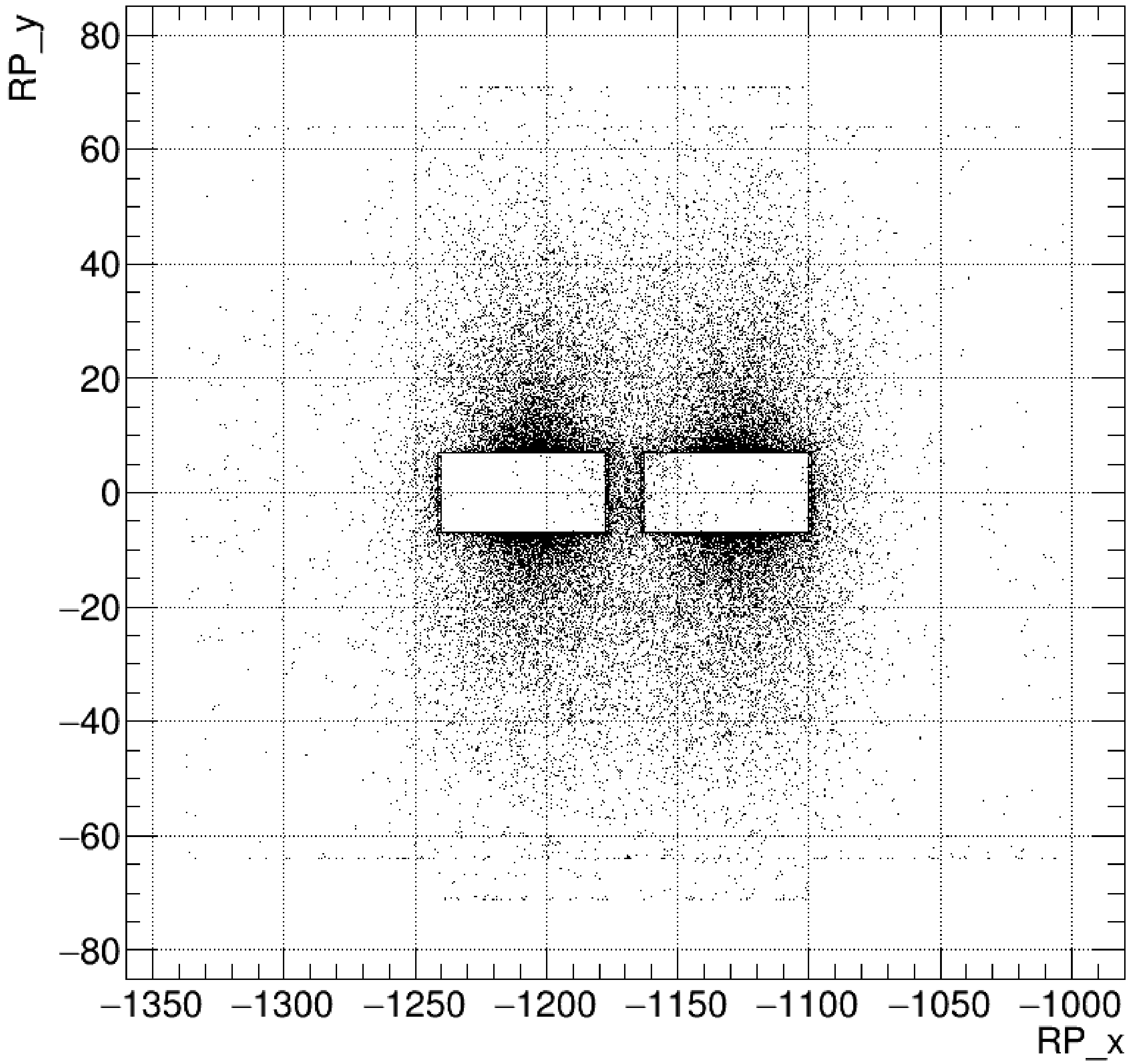
Summary and discussion

- Simulation:
  - Development of detector geometry is frozen unless an unexpected developments we will proceed with the current setup
  - Some issues with RP response (investigating)
- Coherent VM selection and background veto – plots for future TDR
- Semi-coherent events (work in progress) - estimation of beam backgrounds https://github.com/eic/ProtonBeamGas, is ongoing, Clustering of B0 / ZDC has issues, once fixed we proceed to show the resolution plots
- The lowQ2 taggers are not in the EICRecon https://github.com/eic/EICrecon/pull/675, inclusion of low-Q2 region is considered
- t reconstruction – Afterburner bias is investigated, once done, we aim to apply ML to reconstruct t

Backup

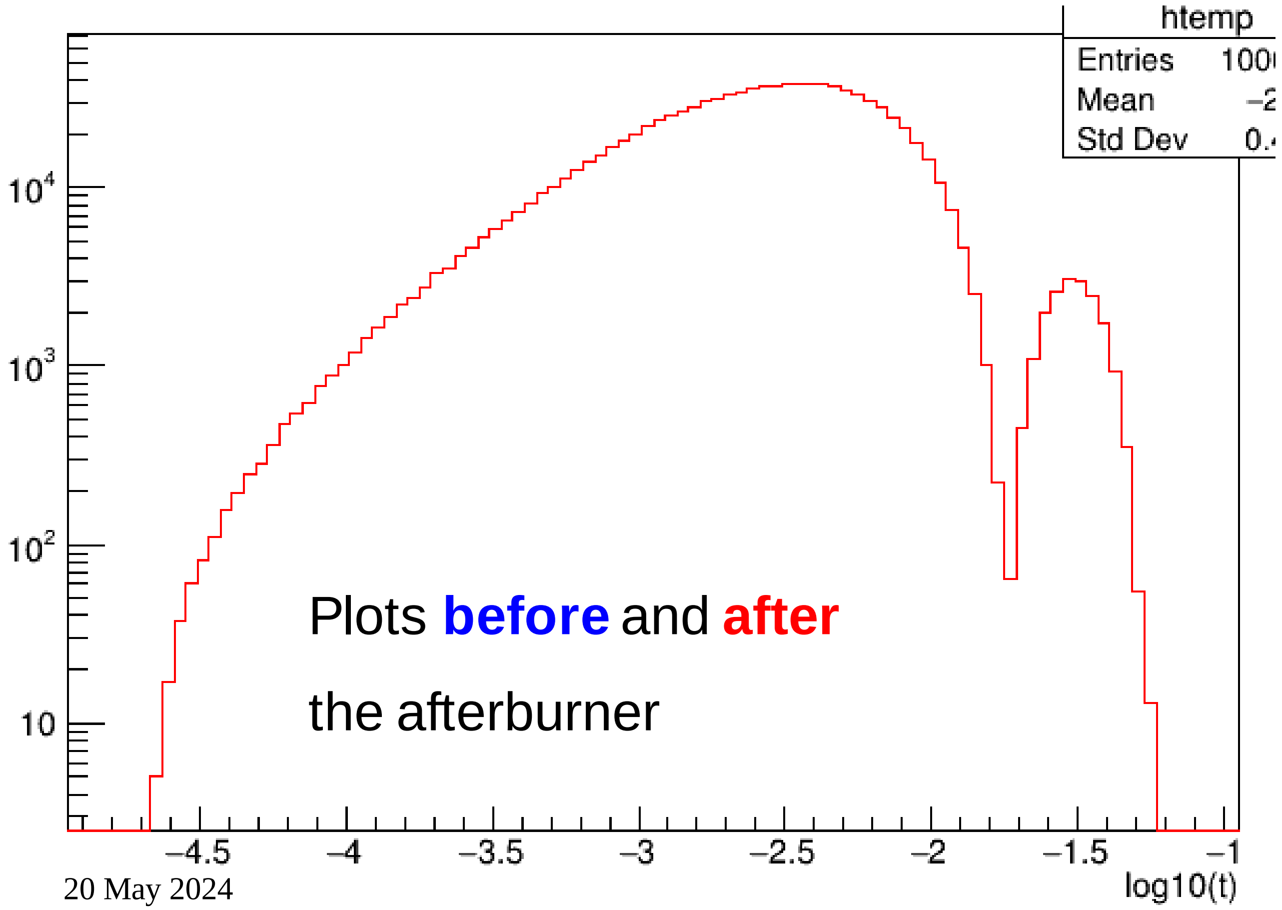
Rejection of forward particles

- RP hit map at the end of the cut flow (only quasi-coherent events are selected)
- Both RP are shown (no RP_z cut is applied)
- Some additional interactions of ions???



Afterburner configuration

Using eic-shell and abconv –p 2 (https://github.com/eic/afterburner)

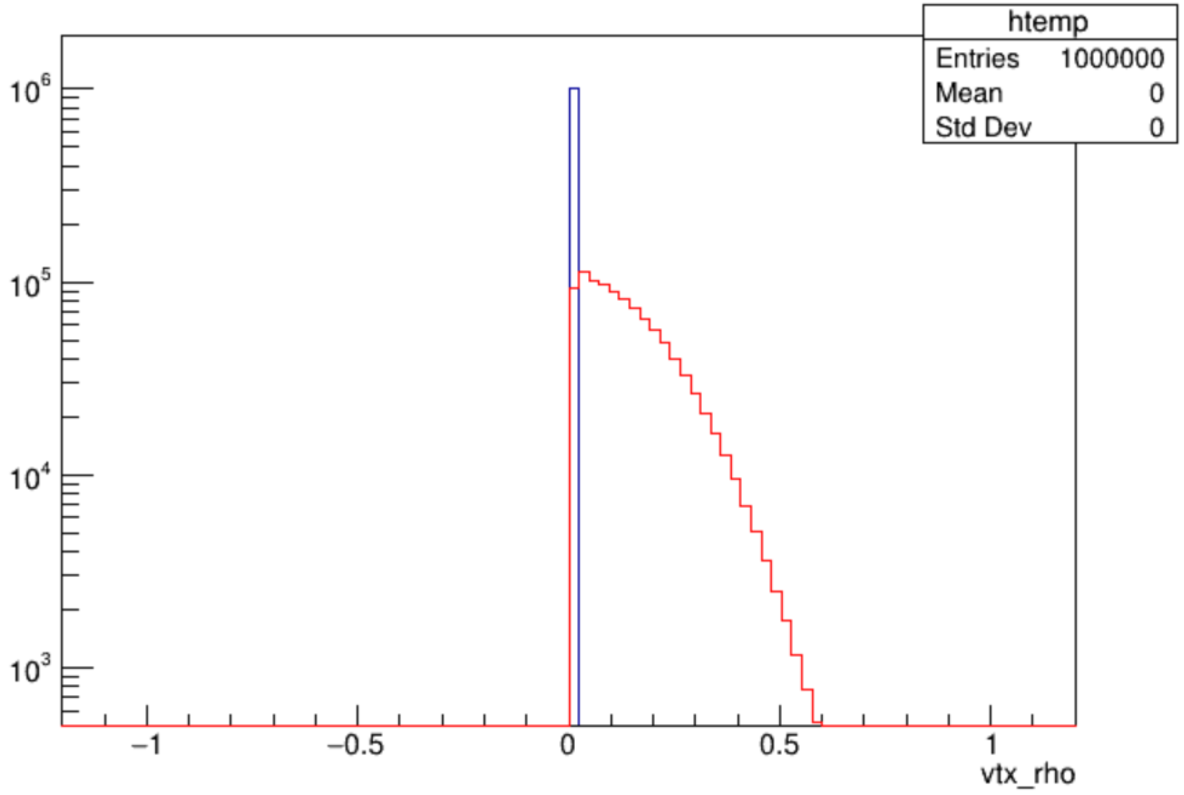


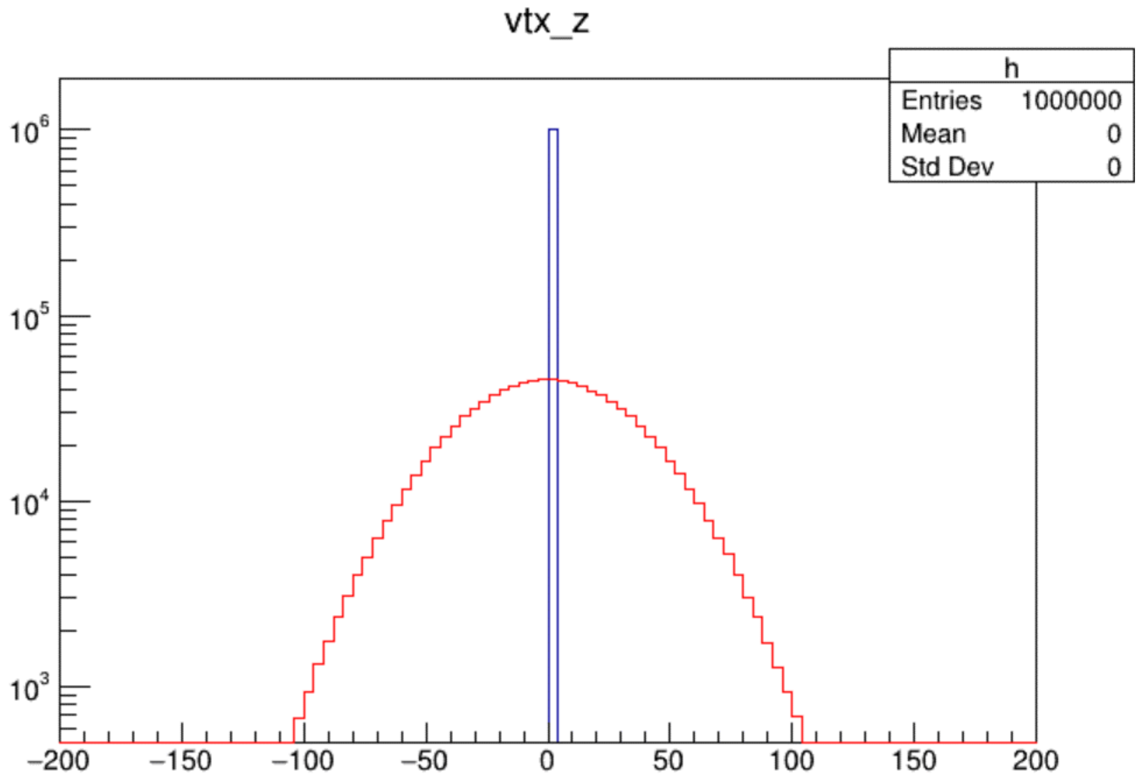
A ab_afterburner_is_used 1
A ab_crossing_angle 0.025
A ab_hadron_beta_crab_hor 500000
A ab_hadron_beta_star_hor 910
A ab_hadron_beta_star_ver 40
A ab_hadron_divergence_hor 0.000218
A ab_hadron_divergence_ver 0.000379
A ab_hadron_rms_bunch_length 70
A ab_hadron_rms_emittance_hor 4.32e-05
A ab_hadron_rms_emittance_ver 5.8e-06
A ab_lepton_beta_crab_hor 150000
A ab_lepton_beta_star_hor 1960
A ab_lepton_beta_star_ver 410
A ab_lepton_divergence_hor 0.000101
A ab_lepton_divergence_ver 3.7e-05
A ab_lepton_rms_bunch_length 9
A ab_lepton_rms_emittance_hor 2e-05
A ab_lepton_rms_emittance_ver 6e-07
A ab_use_beam_bunch_sim 1

Afterburner configuration

Compare vtx distribution stored in hepmc files used in the simulation **before** and **after** the afterburner

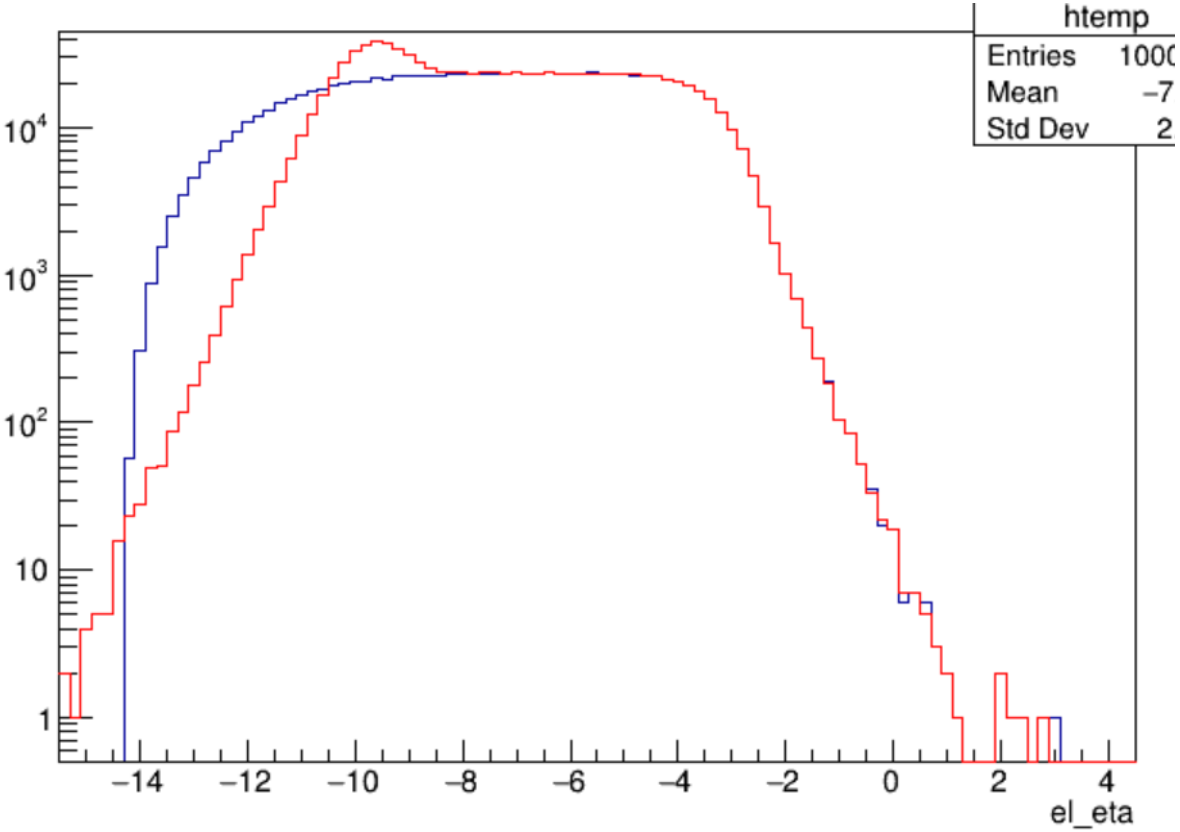
Vertex coordinates (x,y,z,t?) obtained from “E” line in the hepmc files (in mm)

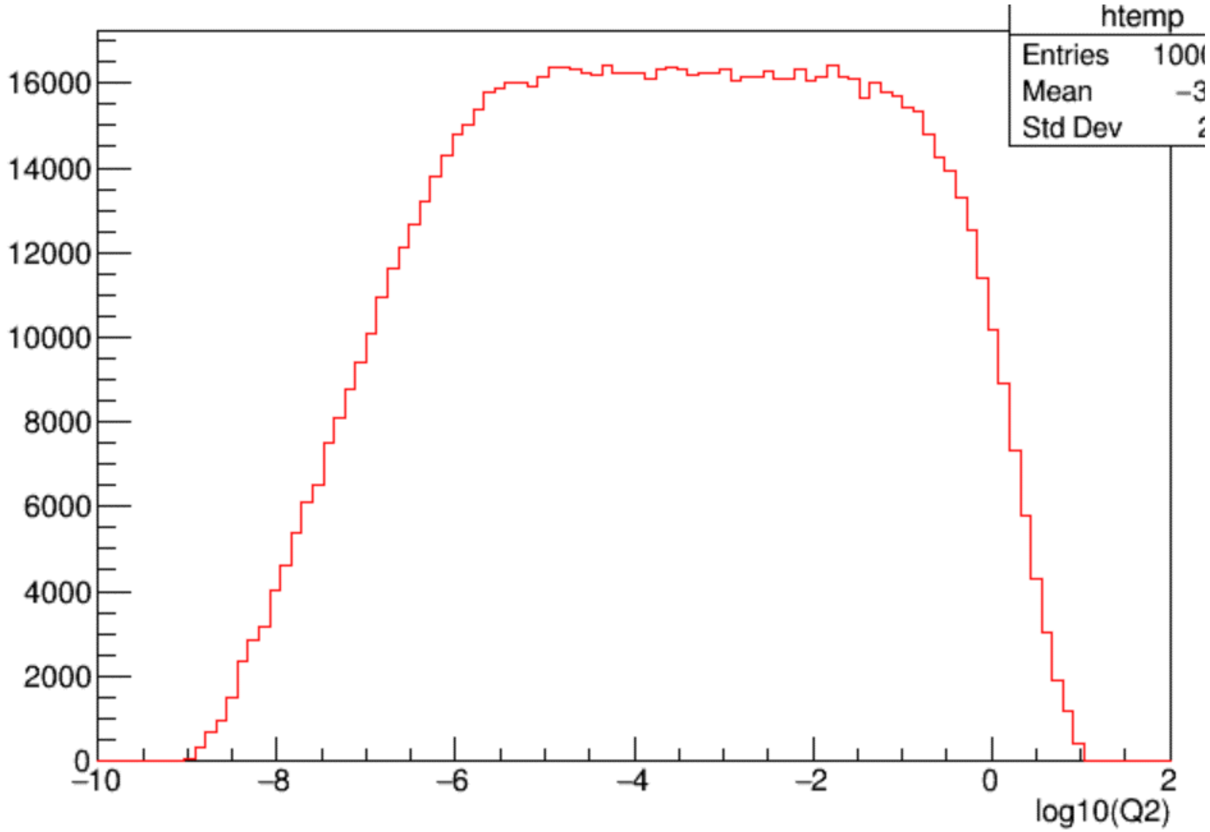




Afterburner configuration

Compare outgoing electron distribution before and after the afterburner

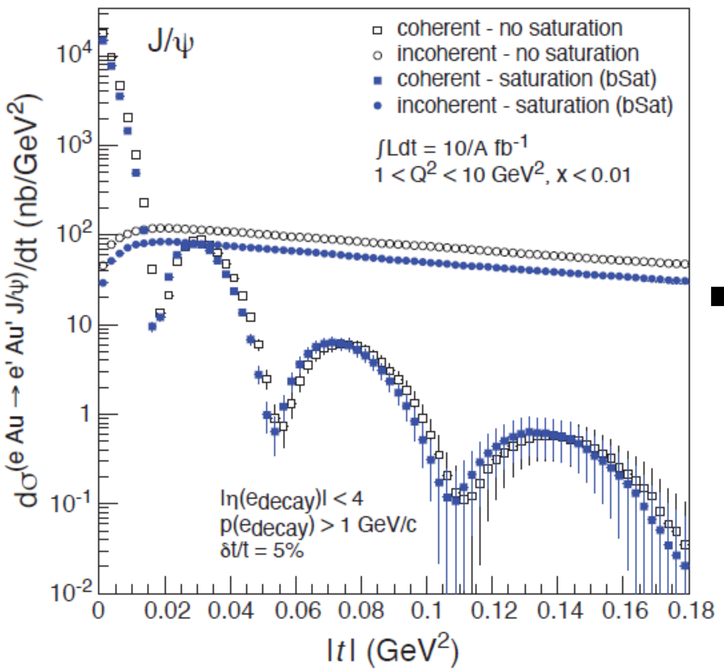




Introduction

Selected (past) studies

- Investigation of the background in coherent J/ψ production at the EIC (2108.01694):



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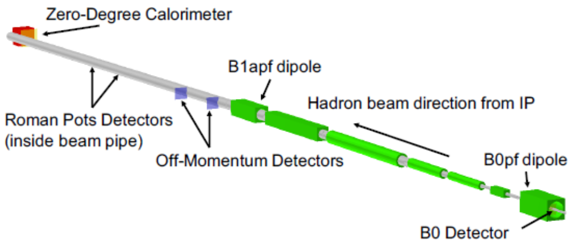

- Veto.1: no activity other than e^- and J/ψ in the main detector ($|\eta| < 4.0$ and $p_T > 100$ MeV$/c$) ;
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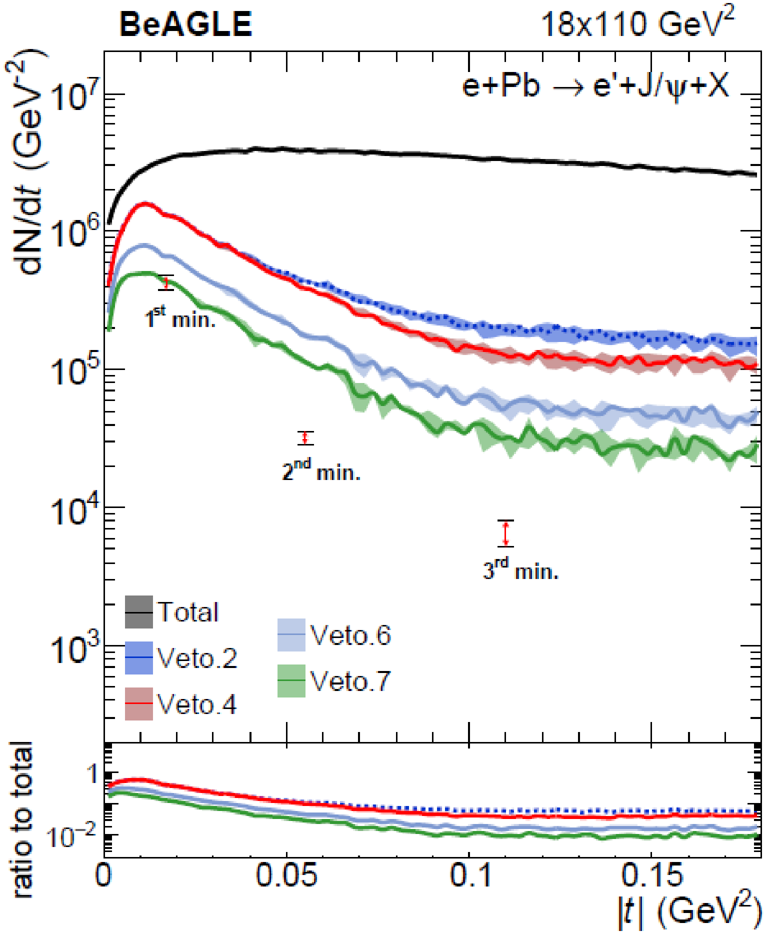
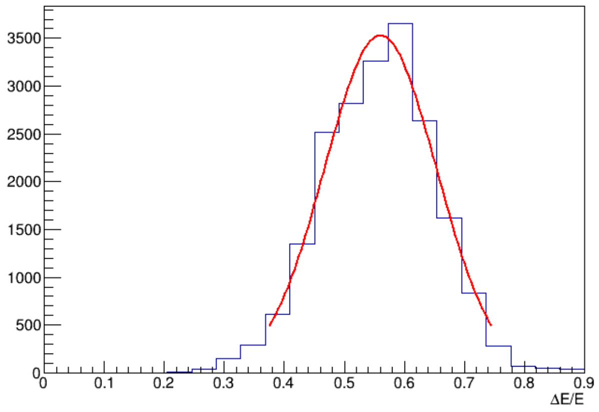


Strong background rejection with FFD at the EIC

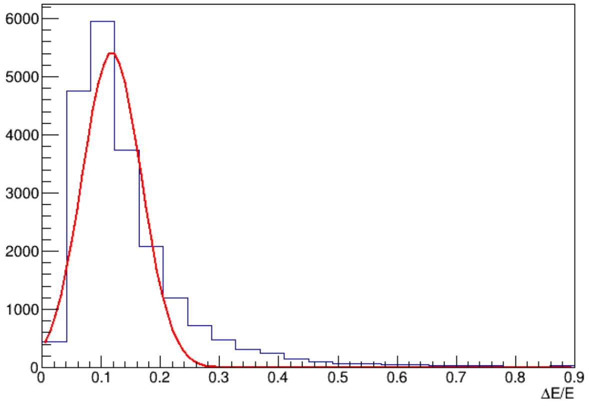
B0 detector performance (EICRecon)

Energy response for θ<13mrad

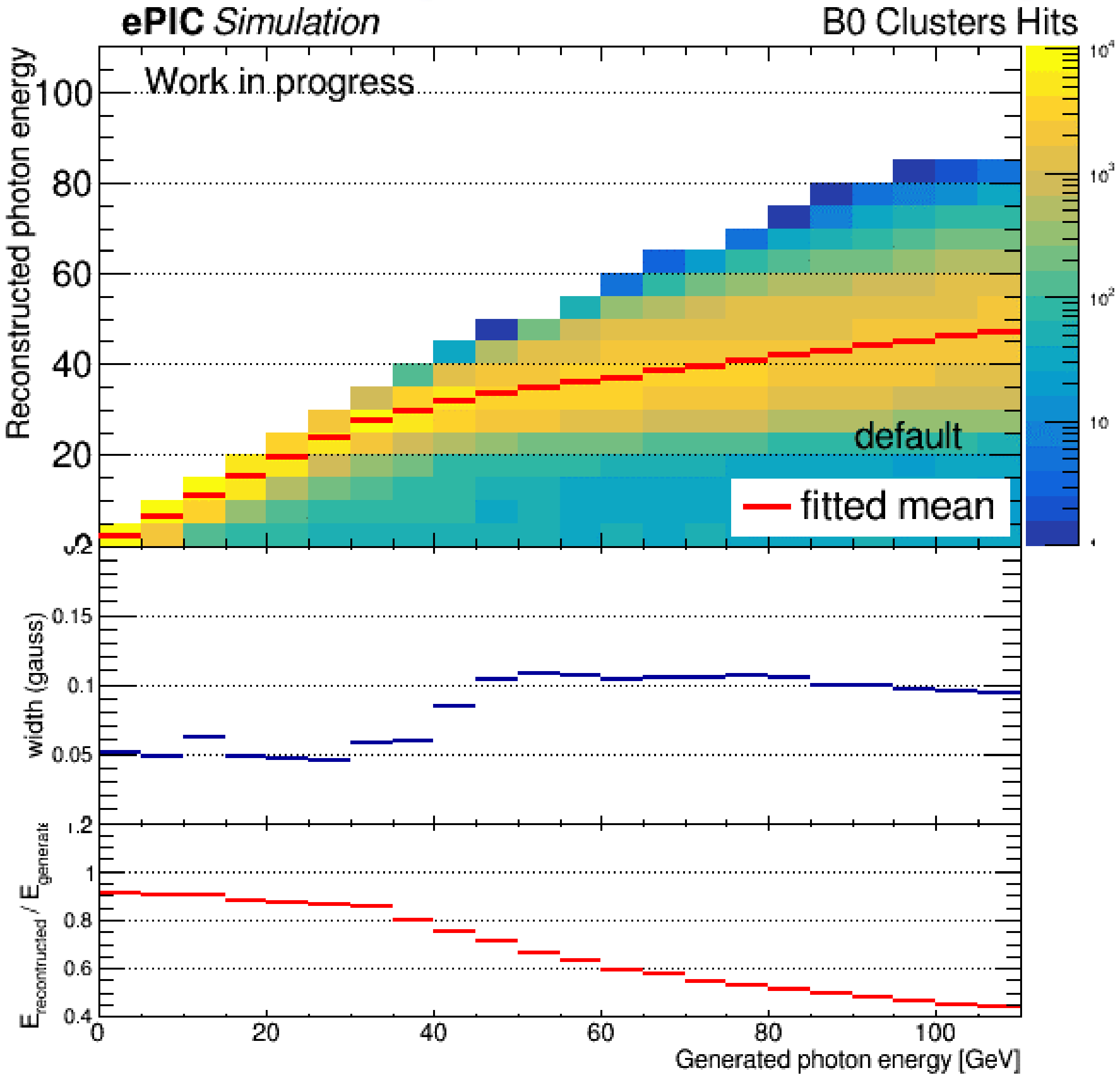
- To study the entire detector's sensitive area beampipe was removed from the simulation.
- When photons interact before the B0ECAL energy response is not defined (fluctuations and bias)
- NOTE: light yields are not included yet (reco level)



E(ph)=110GeV



E(ph)=10GeV

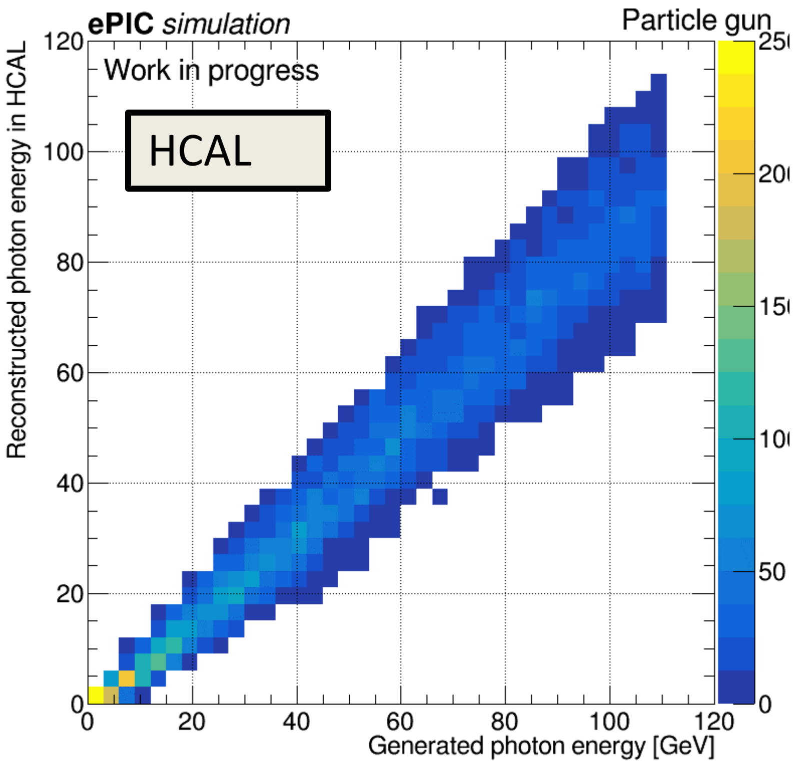


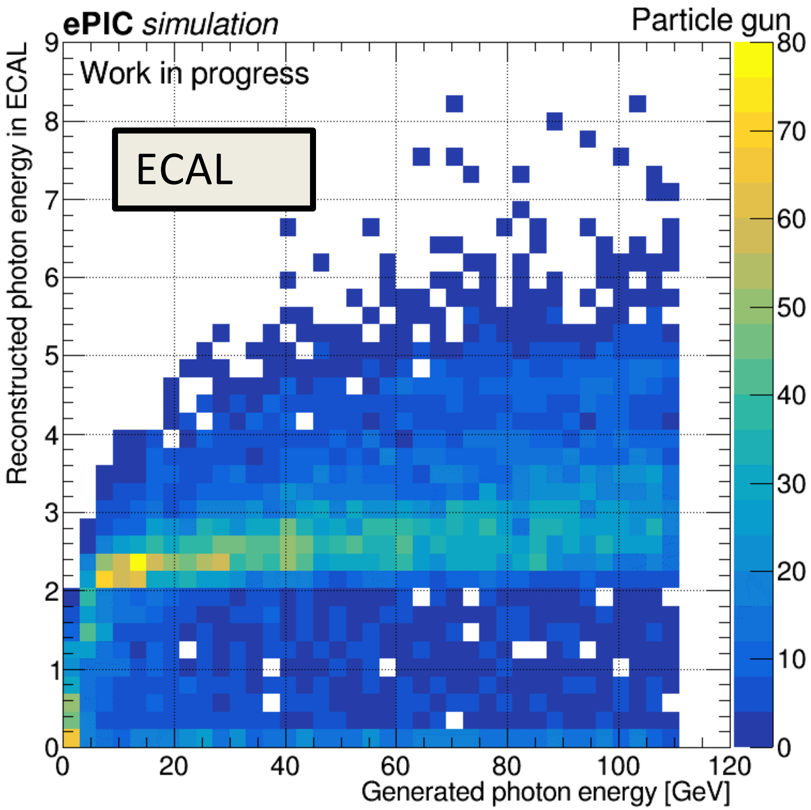
ZDC detector performance (EICRecon)

Particle gun with photons

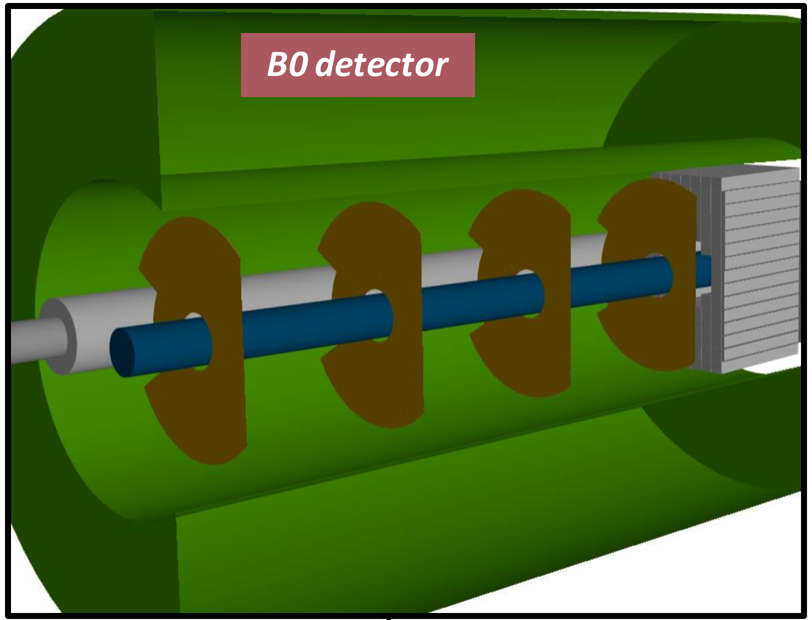
- Photons with θ<2mrad, endpoint>35m.
- Photon energy response from ECAL + HCAL

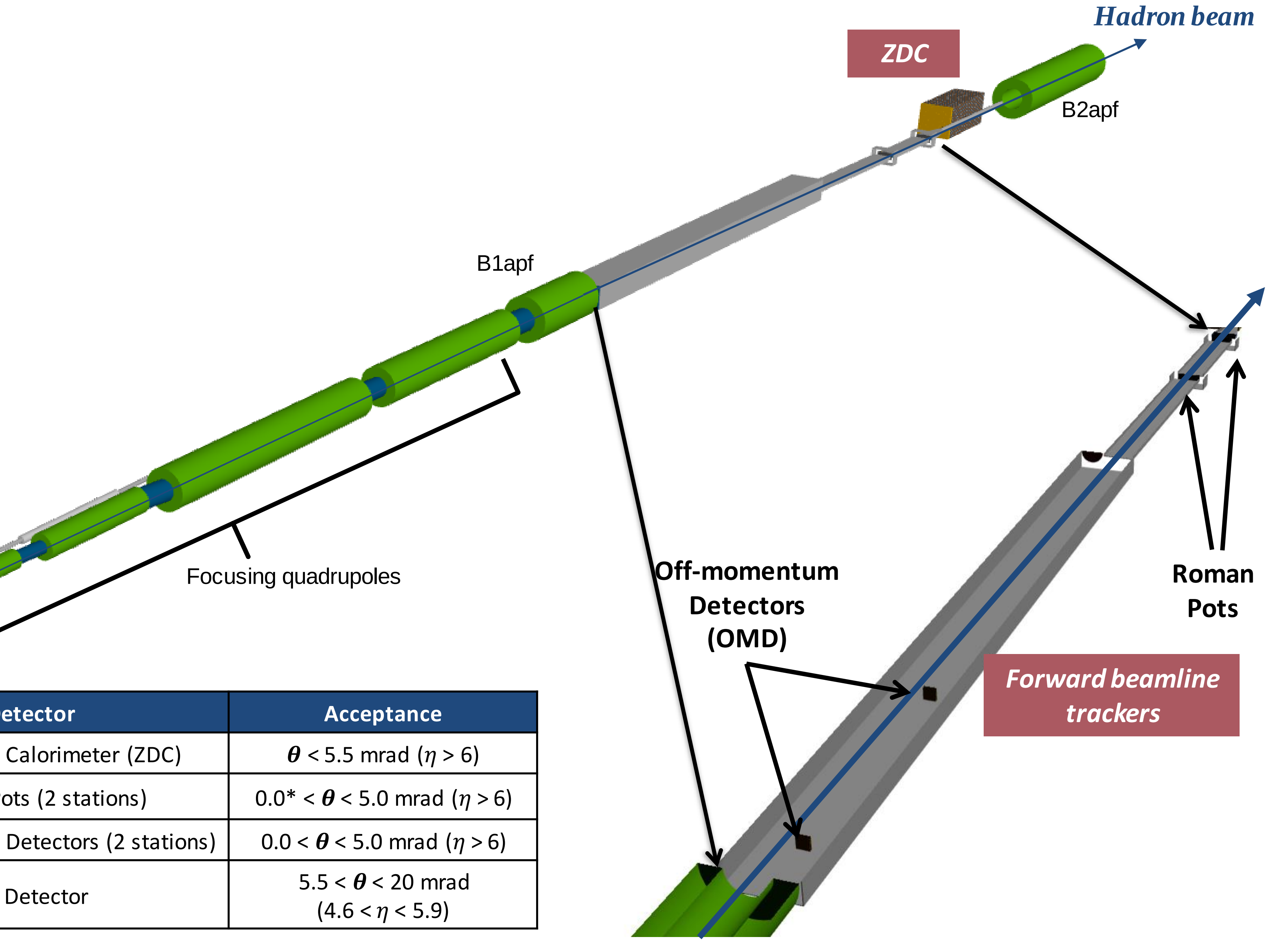
Similar saturation in ZDC ECAL for reconstructed clusters





The Far-Forward detectors





Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	θ < 5.5 mrad (η > 6)
Roman Pots (2 stations)	0.0* < θ < 5.0 mrad (η > 6)
Off-Momentum Detectors (2 stations)	0.0 < θ < 5.0 mrad (η > 6)
B0 Detector	5.5 < θ < 20 mrad (4.6 < η < 5.9)